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Programme de l'hydrogène et du stockage de l'énergie

Hydrogen and Energy Storage Status Report

J.E.A. Alderson, M. Hammerli,
J.R.B. Murphy and J.B. Taylor

April 1985

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HYDROGEN AND ENERGY STORAGE STATUS REPORT

J.E.A. Alderson, M. Hammerli,
J.R.B. Murphy and J.B. Taylor

NRCC No. 24423

APRIL 1985

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PREFACE

This report in general follows the format of the previous April 1984 report. In order that it shall retain a stand-alone value many of the non-changing passages from the previous edition have been retained.

Under the government package of fiscal restraints presented on 8 November, 1985 a decision was made public to phase out the Panel-funded Energy Programs of the National Research Council of Canada by April 1986. This phasing out includes the Hydrogen and Energy Storage Program (H&ES) whose activities are reported in this document.

The following material describes the direction in which the development of the various projects would have ideally taken place under a scenario of continuing future funding. The real situation imposed by the curtailment of this program is indicated in the table of contract funding on pages 144 and 145. Those contracts showing funding which extends into fiscal year 1985/86 are a result of commitments made before the phasing-out of the program was announced and are not indicative of scientific priorities. The program withdrew from all contracts under negotiation at the time of the phasing-out decision.

Within the H&ES program it has generally been the practice to schedule activities into contractual phases between major technical mile-stones and/or decision points. Consequently many activities will be terminated at an intermediate step before achieving their intended final goals.

In view of the above circumstances the state of the various contracted projects may be considerably different from the "Future" activities defined in previous reports.

PROGRAM ORGANIZATION, MANAGEMENT AND FUNDING

The program was funded under the National Energy Program through the Ministry of Energy, Mines and Resources. Technical program management was the responsibility of the National Research Council of Canada and was undertaken as a joint activity of the Divisions of Energy and Chemistry. The accompanying organisation chart (P.3) shows salient features of the management structure.

There were two levels of formal interdepartmental authority. At the executive and planning level was a committee which served to establish priorities and new technical directions. The ultimate authority for funding and overall policy and direction rested with a senior interdepartmental committee called the Panel on Energy Research and Development (PERD).

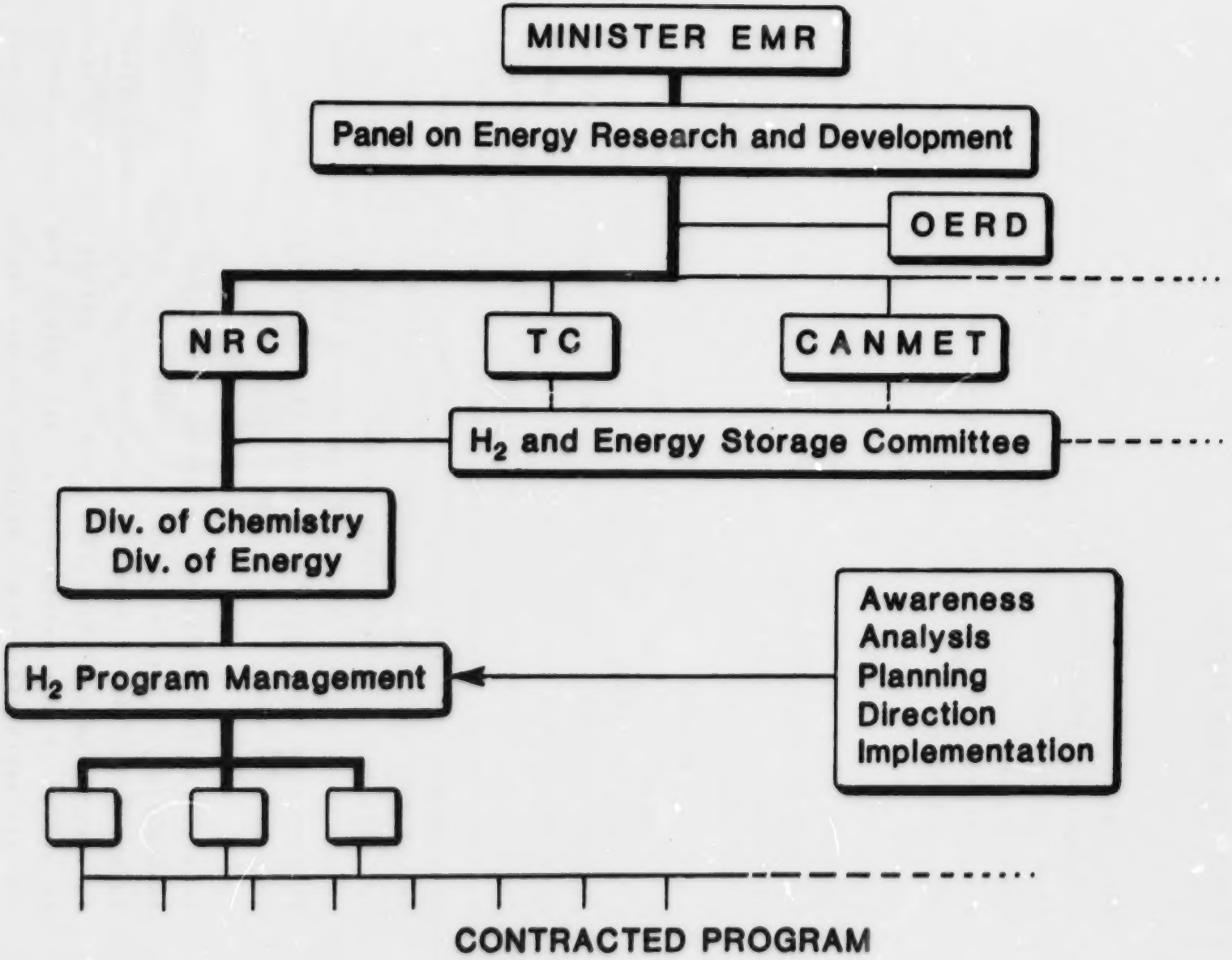
The Hydrogen and Energy Storage activity was one of the many sub-elements of the Energy Research and Development Program and was designated program 5.6. Each of the other sub-elements of the Energy R&D Program were the responsibility of specific government departments. Liaison occurred between departments where inter-related activities were involved. Since there were numerous other routes for funding R&D in Canada, not all the relevant work was under the control of the Hydrogen and Energy Storage Program. Considerable interaction was therefore necessary with the funding agencies to avoid, as far as possible, fragmentation of effort, duplication or conflict. This was largely done on an informal and cooperative basis.

It is further to be noted that the Hydrogen and Energy Storage Program was essentially a directed activity and was not a responsive or granting function. The program direction was of course not established in an arbitrary fashion and a great deal

of consultation both inside and outside government departments occurred as part of an ongoing planning process.

Planned new activities under the program were announced in the Department of Supply and Services R&D Bulletin on a regular basis. Bidders lists were established and constantly updated. Requests for proposals were issued through the Department of Supply and Services and were subsequently evaluated by a team composed of appropriate experts in the field.

Accountability for the program was the direct responsibility of the program managers and strong emphasis was placed on regular and detailed technical revues and written reports. Some of these reports may be available through the lending services of the National Science Library (CISTI). Commercial confidentiality of certain activities precludes the general distribution of some reports. However, this condensed report was issued each year in both official languages by the National Research Council and is available to anyone upon request. Reports were issued in April 1982, 3 and 4. This is the final report in the series.



PROGRAM ORGANIZATIONAL CHART

5.6.1 HYDROGEN SYSTEMS

Much has been written about a future energy system based on hydrogen and electricity produced from renewable or inexhaustable energy sources. The global or widespread deployment of such a system would certainly not occur until well into the next century. However, almost all countries, including Canada, have the primary resource capability to operate such a system and it is conceivable that small scale implementation could occur before the end of this century. However, the use of hydrogen directly in an energy system is at the moment subject to technological limitations. There is no simple way in which hydrogen can replace existing fuels, particularly the liquid fuels upon which our present transportation system relies so heavily. Attempts to force fit hydrogen into such applications are unlikely to have acceptable results. Historically, energy systems have always been replaced by superior systems, not by cheaper systems. There is no doubt that hydrogen possesses many properties which suggest that a superior energy system could be developed. It is the purpose of the present program to investigate, develop and evaluate technologies which are of relevance to the introduction of a hydrogen energy system. A lot of this work will do no more than contribute to a growth of our data base and our technological capability. However, this is the foundation upon which future decisions must be based. Without such knowledge, no meaningful implementation policy can ever be generated.

Even if the introduction of a hydrogen energy system is delayed indefinitely, there will without doubt be a substantial growth in the industrial demand for hydrogen which even now comprises in energy content about 2% of our total energy use. Hydrogen is needed in the manufacture of all liquid hydrocarbon fuels and all synthetic fuels. Hydrogen is also needed in the manu-

facture of ammonia for fertilisers upon which the very continuation of life on this planet is so heavily dependent. Presently almost all this hydrogen is derived from fossil feedstocks. It can equally well be derived by the electrolysis of water and is therefore capable of being produced from a vast range of energy sources such as hydraulic, tidal, wind, nuclear, solar, etc. Technologies for the efficient large scale production of hydrogen by electrolysis are being developed in many countries, including Canada. This program continues to support further development of these technologies. It is now clear that in some parts of Canada electrolytic hydrogen will compete with hydrogen from fossil sources. Supply and economic criteria will ultimately determine the outcome of this situation and whatever substitutions are made will of course be totally invisible to the ultimate consumer.

Thus the future indirect use of hydrogen is in sharp contrast to the direct energy use prospects which are clearly very dependent upon technology yet to be developed. It is, however, inappropriate to segregate the two aspects of hydrogen use and, in fact, a systems approach to the whole topic of hydrogen is desirable. Thus, although at times it may seem that specific elements are receiving emphasis, the general thrust of the program encompasses the whole spectrum of needs reaching from the primary energy source right through to the final end use device. Initially the sucessful introduction of hydrogen into new areas is expected to occur through the recognition of "niches" wherein the special characteristics of hydrogen can be exploited. This approach differs from that taken only seven years ago when it was generally believed that vast markets for cheap hydrogen would exist if only one could resolve the problems which affected the production economics.

5.6.1.1 HYDROGEN PRODUCTION - ELECTROLYSIS

Rationale: Based on the projected make-up of Canadian energy supplies (particularly the large hydroelectric and nuclear component) the electrolysis of water is considered to be the most suitable method for hydrogen production from non-fossil sources in Canada.

Current electrolysers were not designed for the massive projected scale of requirements which will be needed when fossil fuels are no longer the major source of hydrogen. The presently quoted values of 70% electric to hydrogen energy conversion efficiencies can only be achieved at low current densities which implies a reduced output capacity of electrolysers and leads to poor capital use and high hydrogen cost. A large predicted future market for electrolysers provides the incentive to develop high capacity units with optimum efficiency in both economic and energy terms. Advanced designs are being pursued in several countries with a goal of about 85% efficiency by 1985. With advanced electrolysers it will be possible in certain parts of the country to produce hydrogen which will be cheaper than that produced by the steam reforming of natural gas.

State-of-the-Art: The major Canadian effort has been focussed on upgrading a Canadian unipolar design through a Federal cost shared program with a joint corporate venture of Noranda and Electrolyser Corp. The Electrolyser Corp. is the only large producer to promote the unipolar design. The major competition is from bipolar designs, but because the cell process in both designs is almost identical the same upgrading of cell components can be applied to either design. Established foreign electrolyser manufacturers include:

- Lurgi Co. - Germany
- Brown Boveri - Switzerland
- Norsk Hydro - Norway

All are known to have privately funded electrolyser programs. Public funded programs exist in the U.S.A., Japan and European countries and much of this work is performed as national contributions to an International Energy Agency (IEA) agreement for Research and Development on the Production of Hydrogen from Water.

In Canada, part of the hydrogen production activity of the Hydrogen and Energy Storage program has evolved around this IEA cooperative program in which the Canadian contribution is again aligned with, but not confined to, the requirements for upgrading the unipolar design.

The efficiency of electrical energy use and capital utilization are the two major parameters to be optimized for a minimum hydrogen production cost. In electrolyser cell design these parameters can be translated into reducing cell voltage and increasing current density respectively with the added requirement of long life-time for components. The cell components amenable to R&D and related to those parameters are the electrodes, separator and electrolyte. Advanced electrolyser concepts impose severe materials requirements for all these components. New and better materials are critical to the success of this program.

ELECTRODES

The difference between the theoretical minimum voltage and the practically required voltage for gas production at an electrode is called the overvoltage. Reduction of this overvoltage can be effected by use of appropriate depolarizing catalysts. Electrode and catalyst selection requirements are: reduction of overvoltage, low ohmic resistance, capability to handle high current density and long life compatability with a highly corrosive electrolyte environment. The catalyst materials known to be most suited to these technical requirements are noble and semi-noble metals, but the cost and availability of these materials excludes them from use on the enormous scale contemplated.

CONTRACT SELECTION, PREPARATION AND CHARACTERIZATION OF NON-NOBLE METAL ELECTROCATALYSTS FOR THE OXYGEN EVOLUTION REACTION

Atlantic Industrial Research Institute -
Mr. G.P. Wilson - Commenced 1979

OBJECTIVE To identify, prepare and characterize non-noble metal electrocatalysts for the oxygen evolution reaction in electrolysis of alkaline solutions.

PROGRESS Perovskites or related oxide ceramics were earlier identified as potential anode catalysts. Some of the more promising of these compounds have been studied. A major problem was identified in satisfying the requirements for physical integrity of these deposits over large

areas and for periods of time acceptable to electrolyser operation.

CURRENT Samples of a specific perovskite ceramic electrocatalyst ($La_{0.8}Sr_{0.2}Ni_{0.2}Co_{0.8}O_3$) have been fabricated by a spray drying process. Complete reaction of the components was found to require a subsequent heat treatment at 1200°C followed by crushing and sieving which negates the potential advantages of the spray drying approach.

Electrode samples of varying size and quality have been manufactured by using a plasma spray process to deposit the perovskite material on nickel grids. A major limitation has been imposed by the difficulty of maintaining a steady material feed rate for the plasma spray which causes non-uniformity in the final product especially over larger areas for commercial size cells. It is anticipated that this problem will be resolved by the use of a new material feed system which is to be marketed in the near future.

The many plasma deposition parameters have been optimized for the production of adherent deposits while maintaining the correct chemical composition and structure. Adherence is enhanced by first applying a commercial bonding coat to the nickel grids.

Small electrode samples have been used for chemical stability tests of 100 h in KOH at 200°C. Observed small initial losses of material are believed to result from unreacted constituents or "oversprayed powder" which is not well bonded to the sample.

Under electrolysis test conditions overvoltage decreases of 115 mV have been observed (relative to the uncoated nickel grids) for a test period of 100 h.

Larger samples of 15 cm^2 have been made available for testing to the following IEA Annex IV participants:

Noranda Research Centre, Canada, Mr. C. Bowen
SCK/CEN, Belgium, Dr. H. Vandenborre
TH Darmstadt, West Germany, Dr. H. Hoffmann

FUTURE Samples for the Noranda Test Cells, which are operated under this program, would require an improved material feed system to produce uniform coatings over the greater areas required.

CONTRACT THE DEVELOPMENT OF MULTI-ELECTRON CATALYSTS

York University - Dr. A.B.P. Lever and
Dr. C.C. Leznoff - Commenced September 1984

OBJECTIVE To develop stable binuclear and polynuclear phthalocyanines as a basis for multi-electron oxygen reduction catalyst design.

PROGRESS & CURRENT Characterization by microanalysis electronic spectra and mass spectroscopy of many metal-free binuclear phthalocyanines has been completed together with many cobalt and iron complexes. Copper complexes have been prepared. Preliminary correlations indicate that the degree of catalytic activity increases with the degree of coupling.

SEPARATORS AND SOLID POLYMER ELECTROLYTES

SEPARATORS

Rationale: The electrical efficiency of electrolysis increases with temperature due to a lowering of the required cell voltage by 5 mV/°C. An added advantage from increased operating temperature is a reduced necessity for costly catalysts. One of the limitations to increased operating temperatures is the chemical and mechanical stability of the separator materials in the harsh environment of strong alkaline solutions. Increase in operating temperatures also calls for higher operating pressures to prevent boiling of the liquid electrolyte. It appears that the structural configuration of the bi-polar electrolyser is more suited to high pressure operation than is the unipolar cell construction.

State-of-the-Art: Conventional separator materials are asbestos cloths which fail in strong caustic solutions above 90°C. Various materials under investigation as improved separators in advanced electrolysers have resulted from the IEA program activities. These activities have promoted considerable exchange of information and materials. Private company achievements cannot be estimated due to commercial secrecy.

SOLID POLYMER ELECTROLYTE (SPE)

Rationale: The solid polymer electrolyte (SPE) electrolyser is a development of the bi-polar electrolyser with the distinguishing feature that the electrolyte and separator functions are combined in one material. This concept allows a decreased electrode separation which is beneficial in reducing cell resistance; however, there are off-setting disadvantages in construction difficulty (because of lower tolerances allowed in the cell manufacture) and in servicing costs. At the present time the advanced versions of unipolar, bipolar and SPE electrolysers are predicted to be able to produce hydrogen at comparable prices so that any improvements in one of the techniques could give it an edge over the other contenders. A potential improvement in the SPE electrolyser would result from the availability of a low cost solid polymer electrolyte with high physical strength chemical stability and ionic conductivity.

State-of-the-Art: The major proponent of SPE electrolysers has been General Electric in the U.S.A. using the hydrogen ion conducting material "Nafion" developed by DuPont. This activity has been recently sold to United Technologies USA. It should be noted that an alternative and very successful inorganic membrane based on antimonic acid has been developed and applied in advanced bipolar electrolysers by COBELCON of Belgium. This is close to commercialisation. All currently available membranes are perfluorinated compounds containing sulfonate and/or carboxylate groups in the resin. There are four major manufacturers (three Japanese and one American) who vie for a share of the massive market for these materials in the chlor-alkali industry. In this application, the solid polymeric electrolytes are used as sodium ion conductors. In water electrolysis, their acidic characteristics make necessary

the use of noble metal catalysts which are not needed in the conventional alkaline systems. General Electric and Japan have both had considerable success with their cells on fairly modest scales but in spite of being available for several years there has not been marketed any commercial unit larger than laboratory size. The high cost of the separator material is considered to be a major handicap.

Aromatic ionomers have been suggested as possible solid polymer electrolytes. These materials are being investigated by a collaboration of three contractors under the Hydrogen and Energy Storage program, and it is expected that these materials will also find applications in batteries, fuel cells and other emerging electro-chemical devices.

CONTRACT PREPARATION, CHARACTERIZATION AND DEVELOPMENT OF AROMATIC IONOMER MEMBRANES FOR USE IN THE ELECTROLYTIC PRODUCTION OF HYDROGEN

McGill University - Dr. A. Eisenberg -
Commenced May 1980

Daychem Labs. Inc. - Dr. F. Harris -
Commenced May 1980

University of Calgary - Dr. H. Yeager -
Commenced June 1980 Completed September 1984

Ballard Technologies Corporation - Dr. K. Prater -
Commenced September 1984

OBJECTIVES 1. Synthesis of aromatic ionomer materials and investigation of production alternatives for reduction of costs (Daychem).

2. Fabrication of test samples from materials prepared under 1. and evaluation of the mechanical properties (McGill).

3. Membrane testing: measurement of water sorption, electrical conductance and ion transport properties of sample membranes (Calgary/ Ballard).

PROGRESS Early results from this program showed that the aromatic ionomers alkoxycarbonyl substituted phenylated polyphenylenes can be produced and have the necessary technical characteristics for ion conducting solid polymer electrolytes. Indicated conductivities were greater than those for Nafion. Resistance to high temperature alkaline solutions was very good. It was confirmed that the required low resistance of these polymers functioning as separator materials was associated with their microporous and hydrophylic nature.

CURRENT Process improvements aimed at reducing manufacturing difficulty (and cost) have been addressed by devising alternate routes for the production of intermediaries in the synthesis process. Two aromatic systems currently under study are polyphenylated aromatic carboxylates and cyanolated polyquinoxaline. Production scale-up to kilogram quantities has been achieved for 4,4'-oxydibenzil which is an intermediate in the production of both polyphenylene oxide and polyphenyl quinoxaline (PPQ). Biscyclopentadienone monomer synthesis has also been scaled up enabling the preparation of sufficient precursor of the 600 equivalent weight polyphenylene oxide ionomer to produce a film of 0.38 m^2. This

film has a newly developed porous form which in smaller scale evaluations showed solution-like conductivity with a specific conductivity only a factor of two below that of the corresponding electrolyte solution. Reinforced films have also been prepared using PTFE weave and nickel mesh support material. The large sample is now awaiting test under the Noranda Test Cell project.

Cyanolated precursors to PPQ ionomers have been prepared with a range of equivalent weights from 400 to 1400, and pendant polymerizable groups have been added to some to allow thermal cross linking. Preliminary tests show that the materials based on PPQ are stronger than the phenylated polyphenylenes. High temperature casting of polyquinoxaline ionomers is being attempted.

The membrane testing activity formerly carried out by the University of Calgary was taken over by Ballard Technologies as of September 30, 1984. This change of contractor is a first step toward transferring this technology to a Canadian industrial performer. The University of Calgary will continue to be involved at a lower level by subcontract to Ballard.

Materials resulting from this work will also be evaluated by Ballard for use in solid polymer electrolyte fuel cells under a separate contract discussed on page 76.

FUTURE Successful development of low cost solid polymer electrolytes could give Canada a significant advantage in future advanced electrolysers. Effort

should be directed at optimizing the present membrane which is, however, not suitable as a solid polymer electrolyte for water electrolysis since the hydrogen ion on the pendant carboxylate group is too tightly bound. Future work may be directed at replacing the pendant carboxylate group with a sulfonic acid group. An even more attractive option is to develop a polymer membrane which would contain a fixed cation group that could exchange the hydroxide ion readily. Although this is a more difficult task, such a solid polymer electrolyte could form the backbone of an advanced water electrolyser as well as advanced hydrogen-oxygen (air) fuel cell.

CONTRACT DEVELOPMENT OF POLYMERIC SOLID ELECTROLYTE MEMBRANES SUITABLE FOR ALKALINE WATER ELECTROLYSIS

Carleton University - Dr. J. ApSimon

NRC Chemistry Div. - Mr. O. Kutowy -
Commenced September 1980

OBJECTIVE Correlation of structural features of selected polymers with resistance to alkaline hydrolysis. To synthesize and alter existing polymers and to fabricate and evaluate membranes.

PROGRESS Previous work led to an emphasis on polymers based on the polysulfone family prepared by condensing various bisphenol monomers containing carboxylate groups with halogenated aromatic sulfone co-monomers. The position of the acid group at various sites in the chain was studied with respect to its effect on stability to decarboxylation and/or scission of the main chain.

A method was developed to neutralize reactive end-groups on the polymer chain which were suspected of affecting the overall polymer stability to alkaline hydrolysis.

CURRENT A new series of ionomers is under study whereby commercially available polymers may be modified to give ionic substituents by a relatively simple procedure potentially amenable to large scale synthesis.

FUTURE Procedural details and structures of these modified polymers are proprietary and will be disclosed pending suitable patent coverage.

SOLID ELECTROLYTE WATER VAPOUR ELECTROLYSIS

Rationale: Electrolysers operating at higher temperatures than the advanced alkaline electrolysers would have lower overvoltage and no expensive electrode catalysts, with consequent increase in conversion efficiencies and reduced capital costs, respectively. These advantages are offset by the increased difficulty associated with developing materials having the necessary high temperature specifications. A key component to the development of proposed high temperature water vapour electrolysers is the solid state ion-conducting material for the electrolyte/separator function. At the temperature envisaged, this must be a ceramic.

State-of-the-Art: Some high temperature electrolyser programs (e.g., Westinghouse USA) rely on ceramic oxygen ion conductors such as stabilized yttrium and zirconium oxide, which must operate at temperatures in the range of 800 to 1000°C for a sufficient ionic conductivity. Germany is known to have a similar system. The Canadian program is focused on hydrogen ion conductors that can provide an adequate ionic conduction at lower temperatures of about 300 to 400°C. The lower temperature of operation gives a different balance of potential benefits and material development difficulties to those existing for the higher temperature systems.

A further incentive to the development of moderate temperature ion conducting solid materials is the potential use in other electrochemical devices, in particular the application of sodium β aluminas as electrolyte materials in sodium/sulfur advanced batteries and in the use of hydrogen ion conductors in fuel cells. Degradation of electrolytes under operating conditions is a major problem to be solved before these materials can be accepted for commercial device applications.

Although Canada has no program directly involved in the production of Na/S batteries it has developed expertise and capabilities in the separator material sodium/β" alumina, (which is an essential component of these batteries) through the work on ceramic hydrogen ion conductors.

CONTRACT THE SELECTION, PREPARATION AND CHARACTERIZATION OF CERAMIC HYDROGEN ION CONDUCTORS

Queen's University - Dr. M. Sayer
McMaster University - Dr. P. Nicholson
Commenced March 1979

OBJECTIVE The overall objective of this program is the development of low-cost and high efficiency water vapour electrolysers for the production of hydrogen. This work is also in support of Canadian participation in the International Energy Agency Hydrogen Implementing Agreement.

PROGRESS The first phase of this contract identified hydronium β" alumina as a ceramic system with promising ion conducting characteristics, and demonstrated that acceptable conductivities could be achieved. Phase development during calcination and sintering, in the production of hydronium β" alumina, was examined. The influence of magnesium and lithium stabilizing ions, excess potassium ion, and a variation of sodium to potassium ion ratio in the fabrication material was determined with respect to the effects on the final fraction of β phase content and the density of the fabricated hydronium ion β" alumina material. The conditions required to maintain a high β" phase concentration and to produce a high density after sintering were optimized for the

preparation of high density (93% theoretical) hydronium β" material.

The Mixed Alkali Percolation (MAP) theory was further developed, experimentally verified and used. This theory allows a description of the conduction properties of mixed phase, mixed alkali ion exchange which in turn enables the determination of material characteristics required for satisfactory performance and hence the selection of suitable commercial fabrication procedures.

Pre-exchange steps have been designed to optimize the ion exchange process for producing strong polycrystalline hydronium β" aluminas. By replacing the correct amount of sodium ion in the stock material with potassium ion, the material lattice is expanded to allow a non-destructive subsequent ion exchange to the hydronium ion analogue. Two methods of hydronium ion exchange have been examined, i.e., concentrated acid at elevated temperature and field assisted exchange in diluted acid at room temperature.

Sodium yttrium silicate (NYS) and sodium gadolinium silicate (NGS) have been evaluated as polycrystalline three-dimensional hydronium ion conductors. Although more costly raw materials are involved, this could be offset by more amenable fabrication conditions and lower electrical resistance. Hydronium analogues of these materials were produced, to evaluate their hydronium ion conductivity, by using an intermediate potassium ion exchange step as in the production of hydronium β" alumina.

CURRENT An in-depth study of processing parameters has been carried out in order to achieve reproducibility and reliability of the product material on a routine basis. Chemicals and mixing techniques were examined. The effect on the material surface area of various parameters associated with the Spray freeze/Freeze drying process were investigated. The ball milling period was optimized to maximize the surface area. The effects of crucible sizing, temperature and duration of calcining and water absorption on the product powder were measured. Sintering studies were carried out with the object of optimising heating cycles to give a low "β" fraction and at the same time retain good mechanical properties.

Cell developments have allowed operations up to 180°C and it is predicted that temperatures of the order of 300°C will be possible with the present design. A number of problems associated with components other than the electrolyte are limiting performance at the present stage of development, i.e., corrosion and degradation of seals and current collectors.

Discussions with a commercial ceramics manufacturing company, regarding near-term transfer of this technology to Canadian industry, have led to an engineer from the company being located at the McMaster ceramics laboratory to become familiarized with the processing technology. A potential application of the hydronium β alumina ceramic for air detritiation is being studied.

FUTURE Emphasis should be on the development of operating electrolytic cells utilizing both disc and

tube forms, with eventual scale-up for evaluation of material stability under practical operating conditions.

TESTING FACILITIES

Rationale: The current densities, voltage and operational lifetime of electrodes and separators are fundamental to the economics of hydrogen production by the electrolysis of water. As cell sophistication and cost are being increased to improve the energy conversion efficiency, the component lifetime becomes increasingly important. Testing of materials and components is carried out on a small scale during laboratory development but, to ensure that scale-up from laboratory to commercial sizes can be accomplished without reduction in the performance, it is necessary to carry out long term testing on full size components. Testing at a single centre ensures consistency in testing procedures and allows a direct comparison of results from various materials. At the same time it avoids the multiple cost of a large scale testing apparatus for each contracted component.

CONTRACT TESTING OF SEPARATORS AND ELECTROCATALYSTS FOR ELECTROLYSER CELLS

Noranda Research Centre - Dr. R. LeRoy
Commenced May 1979

OBJECTIVE The construction and operation of an alkaline water electrolysis test facility for long term evaluation of separators and electrode catalysts, with sufficient size for the results to be directly applicable to commercial electrolysis equipment.

PROGRESS Currently there are six complete cells available for testing materials, these have ratings of 3000 A over active areas of 0.27 m^2. Four of

these cells are of the original cylindrical design with two more recent additions of plate-and-frame construction. An additional smaller cell is reported below.

Testing continues on materials produced under contract and on materials obtained from other participants in the IEA programs.

CURRENT Evaluations have been made of the cathode catalysts Ni-Cr-B and Ni-Co-Cr-P on nickel screen substrates produced by Gould Manufacturing of Canada Ltd. Results were similar to those previously reported for stainless steel (SS) supported cathodes with the same activation material. None of these materials showed a performance level comparable to that observed from a proprietary cathode of Electrolyser Inc. designated NE-C-20. Silicate addition to the electrolyte (a treatment to reduce asbestos separator deterioration in KOH) was shown to have no adverse effect on this latter cathode material.

Further testing of potassium titanate impregnated PTFE separator material (Japan) showed a deterioration in the produced oxygen purity accompanied by deformation of the diaphragm which appeared to be associated with extended periods on open circuit.

Extremely low anode overvoltages previously claimed for plasma sprayed Ni/SS can apparently be explained as resulting from material which is leached out of the cathode and which benefits the operation in a in a manner similar to electrolyte additives.

Plasma sprayed catalysts have been prepared under subcontract by Sherritt-Gordon Research Centre of Fort Saskatchewan, Alberta. The aluminum leached plasma sprayed cathodes of NiAl (50/50 and 40/60) have provided excellent IR-free overvoltages during preliminary polarization tests, but these have not been matched in continuous operation experiments. Plasma sprayed Ni/SS (90/10) anodes gave impressive overvoltages although somewhat higher than previously reported.

A study has been commenced to investigate the effect on cell resistivity of the gap between separator and electrodes. A new cell has been constructed for this activity, which has a smaller active area ($25cm^2$), and allows additional use for pre-evaluation of materials not available in sufficient sizes for the 3 kA cells.

FUTURE Other materials awaiting test include:

- Polysulfone felts developed under this project
- Nickel oxide diaphragms supplied by Dr. Divisek, Juelich, FRG
- Polymer impregnated asbestos, courtesy of Professor Guiffrè, Milan, Italy
- Commercial grade asbestos from Electrolyser Corp. Ltd., Toronto, Canada
- A proprietary thin diaphragm material from Raychem Ltd., Swinden, Great Britain
- An aromatic ionomer developed under the Canadian Hydrogen and Energy Storage program from E. Besso, Montreal, Canada

Materials requested for testing include:

- Electrocatalyst samples developed by Professor Tseung's group at City University and scaled-up at Inco Alloy Products Ltd., Birmingham, U.K.
- Low resistance PTFE separator material developed by Professor Teschke, University of Campinas, Brazil.

5.6.1.2 NEW TECHNOLOGY AND ENGINEERING

ELECTROLYSIS

Although water electrolysis is an established technology for the production of hydrogen, the commercially available equipment cannot provide hydrogen on the anticipated scale at affordable costs. New electrolyser developments, both inside and outside Canada, are responding to change this situation. Although various aspects of electrolysis research and development are being supported in other elements of the Hydrogen and Energy Storage program, there is a need to integrate such developments into a systems engineering activity.

Initial investigations of new technologies are carried out on a small laboratory scale where proof-of-concept is established. Before full scale commercial plants can be considered, scale-up in size must be carried out, economic production methods must be established, operating conditions optimized, lifetime studies must be carried out and operating requirements and costs determined. During all of these overlapping phases, research and development is a prime factor contributing to the success of final commercialization.

The final assessment of a new system is only possible from observation of a commercial operation so that testing must be carried out under conditions which can simulate this as closely as possible and at a minimum cost. Because of the modular design of electrolysis cells under development, the adequate testing of a small number of full size modules can produce highly reliable information for large scale commercial enterprises, and provide a test bed for continuously evolving system and component improvement.

CONTRACT DEVELOPMENT OF ADVANCED UNIPOLAR ELECTROLYSERS AND THE ECONOMIC RECOVERY OF BIPRODUCT HEAVY WATER

Noranda Mines Ltd. / The Electrolyser Corporation - Dr. R. LeRoy
Commenced March 1983.

OBJECTIVE To carry out a technology development program incorporating research, development and engineering related to opportunities identified for further advances in electrolyser technology resulting from completed work carried out under an earlier program.

PROGRESS New research and development opportunities have been identified as spin-off from a recently completed 6 year program with Noranda Mines Ltd. and the Electrolyser Corporation supported by the Department of Industry, Trade and Commerce. The outcome of this program included:

1. Three full scale 100 kA improved electrolysis cells installed for testing at Hydro Quebec Research Centre, Varennes. The level of advancement of these cells is referred to as Generation I and is based upon modification to proven commercial equipment.

2. Development of a new heavy water recovery process to operate in conjunction with large scale water electrolysers.

3. Identification of a series of new opportunities for further advancement in electrolyser technology.

CURRENT The 2 1/2 year cost shared program includes:

- Commercial development of catalyst materials.

- Development of separator material suitable for evaluation in a 100 kA cell.

- Recommendation of a design for a 100 MW electrolyser plant.

- Installation of two optimized 100 kA cells for test at the Varennes plant.

- A 7.2 kA Generation II advanced prototype has been installed and tested and an evaluation made of the Generation II concept.

- Process engineering design has been carried out in conjunction with Atomic Energy of Canada, Chalk River Laboratories, to define major equipment items and process parameters of a full scale commercial heavy water recovery plant based on the Combined Electrolysis Catalytic Exchange (CECE) process. Basic validification of the process has been achieved in 1984 on the 500 SCF/h pilot unit at Noranda Research Centre. Further information cannot be disclosed at this time for reasons of commercial confidentiality.

THERMOCHEMICAL HYDROGEN PRODUCTION

Rationale: Although water electrolysis is the only commercially developed method for producing hydrogen from non-fossil fuels, there are other conceptually feasible methods and these are potentially suited to countries where electricity costs prohibit the use of electrolysers. Thermochemical hydrogen cycles, even with multiply cascaded steps, have a requirement for large amounts of high temperature heat. The temperature of the heat requirements can theoretically be reduced by increasing the number of steps in the cycle but at the expense of a more complex and capital intensive process. The direct splitting of water by heat, without an intermediate conversion to electricity, remains a challenging field of endeavour.

State-of-the-Art: Various chemical cycles have been devised and evaluated in the USA, Japan and Europe with most of the cycles limited to three or four reactions and maximum temperatures as obtainable from solar concentrators or high temperature nuclear reactors. Because neither of these thermal sources is available in Canada the Canadian interest is low. It has been estimated that the cost of hydrogen from some thermochemical production cycles could be competitive with water electrolysis, particularly where the cost of electricity is high and the appropriate high temperature heat sources are available. Several cycles have been demonstrated in continuous operation at a laboratory bench scale and worldwide interest is still quite strong, particularly in connection with cycles appropriate to high temperature inputs from concentrated solar radiation. The major thermochemical cycles to decompose water into hydrogen and oxygen are the so-called sulfur family processes wherein the common and most difficult step is the reaction involving decomposition of sulfuric acid into sulfur dioxide, oxygen and water.

CONTRACT THERMOCHEMICAL HYDROGEN PRODUCTION

Exergy Research Corp. - Dr. E. Bilgen
Commenced 1978

OBJECTIVE To provide an awareness, reporting and analysis function of international activities in the field of thermochemical hydrogen production, comprising a continuing review of relevant literature and conferences.

To maintain a continuously updated data base on thermochemical cycles.

PROGRESS Reports on progress in the field of thermochemical hydrogen production have been produced for several years. Part of the funding is in support of the contractors, activities in this field on the interface problems at high temperature sources, the form of heat transfer mechanisms and chemical separation requirements. Demonstrated expertise by active research is necessary to maintain credibility and access to international activities. An economic study of hydrogen production from solar energy, collected at a central receiver in conjunction with the General Atomic sulfur iodine cycle thermochemical process, was completed. The cost of hydrogen by this route is estimated as between $60 and $120 per GJ of hydrogen.

CURRENT Analysis work has been directed to the Cristina process which has been operating at Ispra (Italy) under European Communities funded activity. This process achieves the high temperature decomposition of sulfuric acid by direct contact (gas/

liquid) heat exchange, thus avoiding many difficult materials problems. The step is very important as it can be coupled to any of the currently most favoured sulfur family processes.

More recently a modified Cristina process has been examined which retains the advantages of the earlier process but uses oxygen in place of the natural air vector. Theoretical increase in process efficiency is predicted with a reduction of capital cost due to the elimination of heat recovery and turbine compressor components. The modified process eliminates the atmosphere as a reservoir, and in so doing a potential source of environmental pollution is avoided.

FUTURE This activity was expected to continue at the same level.

SMALL HYDROGEN GENERATORS

Rationale: An aspect of hydrogen systems which has received little attention is new small scale generation equipment. Small systems currently manufactured are for a variety of non-energy applications associated with unique chemical and physical properties of hydrogen. Envisaged energy application areas include remote locations possibly with input from intermittent renewable energy sources such as wind, solar photovoltaic and small scale hydro. Development of small scale systems is subject to the same requirements as large systems, e.g., high efficiency, high current density, long life and low cost. Stand alone operation imposes additional technical constraints. High pressure operation would be desirable to facilitate storage without mechanical compression.

State-of-the-Art: The Life Systems static feed water electrolyser concept with its inherent simplicity was identified as a promising basis for future development. This system was originally conceived as an oxygen generating life support system for the American space program. Under sponsorship of DOE, Brookhaven National Laboratories currently have a program with Life Systems to demonstrate the bulk hydrogen generating capabilities of this system. A recent study by NASA (Life Systems Inc. and United Technology Corp. (UTC)) was directed toward a regenerative fuel cell energy storage system comprised of a Life Systems electrolyser and a UTC fuel cell. The Life Systems electrolyser is basically a unipolar alkaline system and could therefore benefit from advances in alkaline electrolyser developments which are already part of the Canadian Hydrogen Program. Unique features of the static feed water concept are the simplicity of the water feed which is effectively self-regulating and tolerant to high water impurity levels.

CONTRACT 5 kW STATIC FEED WATER ELECTROLYSIS SYSTEM

NRC Chemistry Division/Life Systems Inc. -
Dr. F. Schubert
Commenced April 1982

OBJECTIVE A static feed water electrolysis system has been leased from Life Systems Inc. for the purpose of carrying out tests necessary to assess the system capabilities and its potential for modification to meet the requirements of a small stand alone hydrogen generator for energy applications.

PROGRESS & CURRENT Problems encountered during operation under a first year lease have been addressed by the manufacturer and an improved replacement system was delivered for test in October 1983. The replacement was comprised of a twelve cell high pressure module operating at 180 psia which was installed at the Division of Chemistry, NRC, Ottawa. Testing was conducted under the direction of Drs. J.B. Taylor and M. Hammerli. At the end of the lease period the unit was returned to the manufacturer.

FUTURE The performance of this electrolyser type over the two year test period did not justify continuation of testing or evaluation of the project to a further phase.

HIGH TEMPERATURE MATERIALS

Rationale: Materials problems are frequently encountered in new and existing energy conversion systems. For example, in order to obtain high reaction rates and efficiencies it is frequently necessary to operate chemical reactors at high temperatures (600 to 1000°C) where currently employed steels suffer from excessive corrosion rates. Materials capable of operating at these temperatures and under corrosive atmospheres are therefore required. The formulation of suitable alloys requires an understanding of the kinetics and morphological development of corrosion products produced by exposure to various thermal and environmental conditions.

CONTRACT HIGH TEMPERATURE MATERIALS: SULFIDATION AND CARBURIZATION PROPERTIES OF IRON CHROMIUM AND IRON MANGANESE BASE ALLOYS

McMaster University - Dr. W. Smeltzer
Commenced April 1979

OBJECTIVE To develop an understanding of the internal sulfidation and carbonization mechanisms which lead to deterioration of Fe-Cr and Fe-Mn base alloys, and to develop methods for reducing these problems.

PROGRESS Phase I, Sulfidation of Fe-25% Cr in H_2S-H_2 atmospheres (1979-80). Reaction kinetics of Fe-25% Cr were studied over a range of temperatures and H_2S-H_2 atmospheres. The selective attack of chromium in steels to form chromium sulfides with high metal diffusion rates was observed to lead to rapid production of external scales, demonstrating

the non-suitability of these steels for use under sulfiding conditions.

Phase II Sulfidation of Fe-25% Cr - 10% Al in H_2S-H_2 atmospheres (1980-81). The introduction of aluminum into the alloy was found to give 100-fold decrease in the deterioration rates for the low sulfur pressure range but otherwise no significant change.

Phase III, An examination of Fe-25Cr-10Mn-4Al was made on the grounds that the rate of sulfidation of Mn is very much slower than that for Cr metal, and it was found that, compared to Cr, the addition of Mn had a more beneficial effect on the sulfidation properties of iron due to the more protective nature of MnS.

Studies of Fe-25Mn and Fe-50Mn showed sulfidation rates in the latter to be of the same order as observed for pure Mn and an order of magnitude better than for the lower Mn concentration alloy. However, for low sulfur pressures, Fe-25Cr-10Al is still two orders of magnitude better than either Fe-Mn or Fe-Mn-Al.

Although Fe-25Mn-Al showed a decreased initial sulfidation rate with increasing Al concentration, it had been found that under higher sulfur pressures the rate increased due to compact scale being replaced by a porous scale. Further work on Fe-25Mn-20Al for extended exposure shows the oxidation curve to be of sigmoidal form and the rapid sulfidation rate transforms again to a slow protective type kinetics after long exposure.

Phase IV study of Fe-25Mn-Al alloys with a range of Al concentrations demonstrated that sulfidation involved growth of a protective duplex scale of Mn(Al)S and Al_2S_3 which gave way to a transient period of rapid growth at 800°C when nodules were formed beneath the above-mentioned thin scale. Diffusional growth from further exposure was found to be controlled by the transport properties of the innermost layers.

CURRENT Phase IV has continued research toward determination and exploration of the conditions for which Fe-Mn-Al and Fe-Al alloys show superior sulfur resistance compared to Fe-Cr-Al alloys. Determination of the mechanisms of sulfide scale growth on these alloys was carried out using ^{35}S tracer experiments, and the morphology of the scales was defined from metallographic and structural research. Sulfidation experiments were carried out at 750°C in the H_2S-H_2 atmospheres and sulfur vapour.

The sulfide scales formed on the Fe-25Mn and Fe-5Al (wt%) alloys were compact and grew by predominant outward cation diffusion. Highly porous scales formed on the Fe-25Mn-5Al alloy which grew by permeation of sulfur vapour through these scales. The scale formed on the Fe-25Mn-20Al alloy was associated with growth of an Al_2S_3-$(FeMn)Al_2S_4$ protection layer on the alloy by sulfur and metal diffusion beneath the above type of porous scale. This ferritic F-25Mn-20Al alloy thus developed a fair resistance to sulfidation due to the occurrence of a sigmoidal type reaction curve due to breakdown of the initially formed MnS protective film and growth of a porous scale until healed by growth of

the innermost Al_2S_3-(FeMn)Al_2S_4 layers. The sulfide layers in these different scales were classified by means of the MS, M_3S_4, and M_2S_3 type sulfides in the Fe-Mn, Fe-Al and Fe-Mn-Al sulfur systems.

The final annual 1984-85 report is under preparation.

FUTURE The Hydrogen and Energy Storage support of this work was terminated in March 1985 as a result of change in priorities and funding availability.

5.6.2 HYDROGEN UTILIZATION

This sub-program encompasses storage, transmission, distribution and end-use of hydrogen. Of particular interest are those potential new end-use opportunities which might evolve when the supply of hydrogen is separated from fossil fuel primary sources. Hydrogen may be employed directly as an energy carrier, indirectly as a chemical feed stock for fuel production, or as a chemical feed stock.

The direct use of hydrogen as a fuel is uneconomic at present because the cost of hydrogen is necessarily greater than the cost of natural gas from which it is predominantly produced. In certain geographical areas, it is expected that non-fossil derived hydrogen could compete with fossil fuels in the future, especially if advantage can be taken of the unique properties of hydrogen compared to other available fuels. In some industries, by-product hydrogen is already used as a fuel.

For mobile applications, a major technical impediment to hydrogen use is the difficulty of storage resulting from its low specific energy density; also gaseous hydrogen lacks the convenience of liquid fuels for which a massive widespread distribution infrastructure exists.

Liquefaction of hydrogen overcomes to some extent these problems, but introduces a new set of production, storage, distribution and safety problems, some of which are associated with the very low temperature of liquid hydrogen.

Synthetic fuels closely resembling the currently used petroleum liquids can be manufactured, but they are expensive and rely for the most part on exhaustible fossil sources for the carbon content. However, alternate fuels such as alcohols, although

requiring a carbonaceous feed stock, can be produced with greater energy efficiency and at lower cost.

Other possibilities include liquid fuels with zero carbon content such as ammonia (NH_3). The nitrogen constituent is readily available from air and as a consequence this fuel can be completely independent of fossil sources.

5.6.2.1 HYDROGEN STORAGE

HYDROGEN STORAGE - LARGE SCALE

Rationale: It is anticipated that in the future there will be large scale use of electrolytic hydrogen as an energy storage medium or for chemical feedstock. For convenient and economical management of this hydrogen, high capacity bulk storage capabilities will be necessary to interface between supply and demand. Such facilities are not currently very numerous because the current demand for hydrogen in most applications is satisfied by hydrogen derived from hydrocarbon sources. These hydrocarbons are converted to free hydrogen as required so that the hydrocarbon source material functions as the hydrogen storage medium. In many aspects the bulk storage methods for hydrogen are expected to be similar to methods used for storing natural gas in either the gaseous or liquid form. Because there are significant differences in the properties of these materials, the differences and their ramifications with respect to the applicability of storage methods must be identified together with actions for the resolution of foreseen problems. The majority of documented experience with large scale hydrogen storage is associated with the American space program in which liquid storage is favoured because it has the highest gravimetric energy density of any fuel. Imperial Chemical Industries in the UK have stored hydrogen underground in salt caverns and Gaz de France has also had experience with hydrogen in aquifers.

A number of studies have been performed on the technoeconomic aspects of bulk hydrogen storage. These studies are of a general nature and the parameters and constraints used do not reflect specific Canadian needs.

CONTRACT BULK STORAGE OF HYDROGEN

CANATOM Inc. - Mr. L.A. Phillips

Commenced June 1983

Subcontractors - Institute of Gas Technology

OBJECTIVE To investigate the available options and opportunities for large scale storage of hydrogen in Canada.

PROGRESS The scope of this project includes above ground storage in pressure vessels or cryogenic containers and underground storage in rock caverns, salt domes or permeable rock.

A detailed economic and technical analysis has been carried out for the various methods of gaseous or liquid hydrogen storage in large quantities. The approach taken for this study was by consideration of selected plausible Canadian scenarios in order to include site and application specific considerations which impact heavily on system economics.

The five chosen scenarios are listed on page 45 together with the storage capacities required, storage cycling rates and the necessary electrical generating capacity.

The scenario treatment was supplemented with

- review of various storage modes
- geological studies related to specific siting
- recovery of storage energies for compression and liquefaction

- safety and loss control. This subject was treated by comparison with established procedures for natural gas and liquid natural gas, modified by consideration of the known differences between the properties of hydrogen and methane.

Major findings of this study include the following

- Large cavern storage is in general an order of magnitude less costly than high pressure tubes and cylinders or cryogenic liquid storage.

- The largest single influence on the cost of storage is gas throughput, and in the extreme case a large cavern with low gas throughput can have higher storage cost than high pressure cylinders with greater cycling rate.

- A major factor is the cost of hydrogen which for electrolytic production depends on the cost of power which is in turn related to the service factor for the power plant.

- Where the hydrogen end-use is necessarily liquid hydrogen, the only reasonable storage is in the liquid form.

- The single major technical concern identified was the pressure limitation of carbon steel (1000 to 1200 psi). Increase in this limit would allow proportionally decreased

storage volumes, thereby reducing costs and increasing the choice of storage mode and location.

This report demonstrates the fallacy of applying generalized costs to storage and reinforces the need to include specific site and application considerations. The final report on this work was delivered in July 1984.

CURRENT AND FUTURE No further work on bulk storage is anticipated at present; however, contract work relating to strength of materials was carried out under safety activities of this program.

SELECTED BULK STORAGE SCENARIOS

STORAGE MODE	HYDROGEN USE	LOCATION	CAPACITY (Tonne)	CYCLE (Tonne/Day)	ELECTRICITY MW
HIGH PRESSURE VESSEL	SMALL INDUSTRY	NOT SPECIFIC	0.3	0.3	0.8
CRYOGENIC LIQUID TANK	AIR TRANSPORT FUEL	MIRABEL	1000.0	32.5	150.0
SALT CAVERN	TIDAL ENERGY RE-TIMING	DORCHESTER N.B./ CUMBERLAND BASIN	160.0	2 x 80 charge 160 Discharge	1000.0
HARD ROCK CAVERN	PEAK SHAVING FACILITY	ROUTE-JAMES BAY/ QUEBEC INDUSTRIAL REGION	160.0	160.0	1000.0
POROUS MEDIA (Depleted Gas Well)	HEAVY OIL UPGRADING	WHITESIDE-VICTORIA GAS POOL	2200.0	113.0 6 Month Charge 6 Month Discharge	475 (12 month) 475 (6 month)

HYDROGEN STORAGE (SMALL SCALE)

Rationale: If hydrogen is to be used as an energy carrier in a complementary role to electricity then its prime function would be to provide an energy storage capability. The problems of energy storage are most severe for transportation fuels which are required to have high volumetric and gravimetric energy densities. It is not expected that there will be found any single method of hydrogen storage that will be suited to all potential end uses. In order to ensure that the most appropriate storage is associated with any emergent requirement it is necessary that generic studies be carried out to adequately characterize the various available and conceptual storage methods. Transportation fuels are currently almost entirely hydrocarbon liquids which have proven qualities for this application. Hydrogen from non-fossil sources can be used to synthesize liquid fuels but in general the processes have low energy conversion efficiency, are costly, and require carbon input on a scale which can only be supplied from depletable fossil deposits. In the long term, alternative energy storage will be required to circumvent this fossil dependence.

MICROENCAPSULATION

State-of-the-Art: A method for storing hydrogen under high pressure without conventional heavy pressure vessels is to contain the hydrogen in glass microcapsules which can be manufactured with a capability to withstand high internal pressures. The microcapsule loading method depends on the variation of the hydrogen permeability of glass with temperature. Hydrogen is diffused into the microcapsules under high pressure at increased temperature. Subsequent reduction of temperature and pressure leaves high pressure hydrogen trapped inside for release at any time by the application of heat. Some investigations of this storage mechanism have been carried out in the USA using commercially available microspheres. The DOE-funded American activity was terminated at the end of 1981. The properties of the microspheres were not optimized for the application. In the light of new ideas on microencapsulation, the results of the American work are no longer considered to be sufficient reason for rejecting this storage concept. Further studies are judged to be required before any decision can be reached.

CONTRACT EXPERIMENTAL EVALUATION OF HYDROGEN STORAGE IN GLASS MICROCAPSULES

Ontario Research Foundation - Dr. S. Johar
Commenced December 1981

OBJECTIVE To conduct an experimental program from which an evaluation can be made of the potential use of glass microcapsules for hydrogen storage.

PROGRESS A proof of concept first phase study was completed in March 1983. This study indicated that

for high storage densities silica glass was the preferred microcapsule material. Major considerations in this choice were the material strength and a suitable temperature dependence of hydrogen permeability. These are the parameters influencing storage density and rate of delivery, respectively. A major problem in microsphere encapsulation was shown (in the recent American program) to be capsule breakage occurring during the charging process. It resulted from non-uniformity of size and shape (and therefore strength) both between spheres and within individual capsules. In the present project, hollow fibre capsules were used because it was anticipated that a greater degree of control could be maintained over the microcapsule quality and reproducibility during manufacture. This assumption was partially guided by experience reported in fibre optics manufacturing techniques.

A commercial fibre optics drawing apparatus was modified for drawing the thin walled hollow silica fibres which were tested for axial and burst tensile strength. Etching procedures were developed and evaluated for wall thinning and strength improvement, and end-sealing techniques were developed. A charge/discharge system with capability to 6000 psi and 300°C was designed and constructed.

CURRENT Storage densities in excess of 2½ weight percent of hydrogen stored per fibre have been attained; however, this has been at the cost of a high mortality rate amongst the fibres. A storage threshold is observed for the number of fibre failures. Below this threshold storage density a very low fibre failure is observed and above it a

high fibre failure occurs. Glass breakage is most commonly initiated from flaws causing stress concentration, and considerable effort has gone into control and optimization of fibre drawing parameters in order to reduce the formation of such flaws. The allowable drawing conditions for hollow fibres are severely limited, by comparison with those available to the drawing of solid fibres, because it is necessary to avoid collapse of the hollow centre. It appears that the simultaneous requirements for maintaining the hollow centre and reducing the number of flaws leads to hollow fibre strengths that are considerably inferior to the values currently achievable for solid fibres.

The thin walls and high pressures required for high storage densities also increase the susceptibility to a chain reaction of breakages where a single capsule of inferior quality can instigate breakage of surrounding capsules, etc. Some progress has been made in controlling this effect by applying protective coatings to the fibres. The possibilities of rigid encapsulation of either fibres or balloons is also being studied.

Estimates of production costs for hollow silica fibres are very high due to the high temperature required for silica fabrication which causes materials problems and results in a labour intensive process. At present, potential applications for this technology are being sought in the three areas of hydrogen storage, gas separation and hydrogen purification.

<u>FUTURE</u> If suitable application areas are identified

where this technology might have an advantage over alternative concepts, then the microcapsule characteristics were to be optimised for that specific use. In particular, different glass with reduced performance was being considered to reduce the production cost. As a result of this work a considerable expertise in the fabrication of hollow fibres has been acquired; spin-off opportunities will be investigated outside this program.

HYDRIDES

Rationale: Gaseous hydrogen is a particularly inconvenient energy carrier for mobile applications. Liquefaction and compression can be used to provide acceptable storage for some applications. In addition, it is possible to react hydrogen reversibly with certain metal alloys to give solid compounds containing up to about 5% by weight of hydrogen. These alloy metal hydrides have a variety of characteristics which also allow their application to hydrogen compression, pumping, heat pumping and heat storage. In order to develop these systems it is necessary to have available suitable alloys with appropriate characteristics. To a certain extent it is possible to control some of the operational characteristics by alteration of the alloy composition. A great deal of this work is empirical in nature and the quest for a full understanding of these materials continues. Hydrides are in general very attractive from the point of view of safety. They are unattractive from the energy density point of view and further practical problems result from the adverse effects of impurities in the hydrogen. Recent improvements in performance have been made in terms of resistance to impurities and speed of hydrogen uptake. There have also been significant improvements in the heat transfer capabilities of hydride beds which allows the rapid cycling necessary in compression and heat pumping applications.

"IN HOUSE" PROGRAM

METAL HYDRIDES

Chemistry Division, NRC - Dr. J.J. Murray
Commenced 1978

OBJECTIVE To obtain reliable and accurate data on practical alloy hydride systems. To add to the scientific data base on these systems, maintain contact with the worldwide work in this field and to develop new techniques and new materials relevant to the study and use of these materials. The program is also used to maintain a detailed awareness of work being carried out elsewhere and of engineering developments and new applications involving hydrides.

PROGRESS This program is conducted entirely in-house by the NRC Division of Chemistry. There has been established a facility for the preparation of alloy specimens of the requisite quality for these studies. Reactions of these alloys with hydrogen are now studied by measuring pressure changes, heat changes (calorimetry) and structural changes (X-ray diffraction). The bulk of the work to date has been done by the first two techniques and has produced much new and interesting data particularly in the thermodynamics field. Many complex phenomena occur during the hydriding and dehydriding of the alloys which ultimately influence the system performance in a practical situation.

CURRENT At present the work is aiming to quantify these effects. Important correlations are expected to be examined as more data become available from the structural studies. In addition to X-ray analysis, work has now started on structure determination by neutron analysis in conjunction with Atomic Energy of Canada Ltd. Alloys studied to date include Mg_2Ni, FeTi, FeTiO, $LaNi_5$ and $CaNi_5$. Although of practical interest because of the low weight and relatively low cost, the magnesium alloys have proved particularly difficult experimentally because of the extremely slow speed of reaction with hydrogen.

FUTURE This is an ongoing project within the Chemistry Division of NRC, Ottawa. The program is scheduled to continue at the present level of support (four person years).

5.6.2.2. LIQUID HYDROGEN-CARRIERS

Rationale: The existing infrastructure for transmission, distribution and storage of vehicle fuels is almost entirely designed for a liquid fuel based on oil. The application of electricity to transportation could be accomplished by the use of electrolytic hydrogen to produce liquid fuels compatible with existing systems and infrastructures. Apart from synthetic gasoline-type liquid fuels, the number of liquid fuels suitable for consideration as hydrogen carriers is very limited. Methanol and ammonia are the major current contenders. These liquids have appreciable advantages over liquid or gaseous hydrogen in terms of safety, handling characteristics and ease of storage. End-use is not necessarily limited to mobile applications. Advanced methods of large scale production are well established for existing non-energy related markets. Liquid hydrogen-carriers can be burnt directly in an internal combustion engine or alternatively hydrogen can be readily obtained from these compounds. In the latter case, it is necessary to justify the added complexity and cost of the intermediate step of conversion to hydrogen.

The nature of the selected carrier, together with the engine characteristics, dictates the fuel processing requirements. The overall combined system performance must justify development of this concept. In fact there is strong supporting evidence from the point of view of efficiency gain alone. Waste engine heat used to drive the decomposition reaction in many cases actually increases the energy content of the hydrogen fuel entering the engine. Additionally, the engine efficiency at low power settings can be increased by taking advantage of the flammability range of hydrogen in a way which is not possible with gasoline.

The eventual possibility of using hydrogen in a fuel cell/ electric drive also offers potential for efficiency gain, and here the use of liquid carriers as direct fuels is less likely so that on-board conversion to hydrogen will be required.

State-of-the-Art: Various liquid carrier options and system designs have been proposed and some vehicle systems have been assembled and tested with internal combustion engines. Evidence of considerable efficiency gains have been reported from Japanese and American work in which methanol was cracked to $CO + H_2$. The problems of catalyst durability and resistance to contamination by impurities are not solved. The reactor is of course not self starting and various techniques have been tried including auxiliary heating and dual-fuel configurations. In addition, problems remain with regard to the achievement of maximum design power output from the engine.

Very much less is known about ammonia and cracked ammonia for use in combustion engines. The use of ammonia as a fuel dates back to the 1940's when it was used for public transit buses in Belgium. A resurgence of interest occured in the 1960's under the US Army Material Command when ammonia was considered as part of the "energy depot" concept. No insurmountable difficulties were identified that would restrict the use of ammonia as a fuel, but this project was discontinued because the mobile nuclear reactor for the primary energy source was never developed.

A study on the safety aspects of ammonia as a vehicle fuel was carried out by Chemetics International for this program and reported in 1984.

CONTRACT REPORT ON THE USE OF A LIQUID HYDROGEN CARRIER AS A VEHICLE FUEL BY ON-BOARD GENERATION OF HYDROGEN

Ontario Research Foundation (ORF), Centre for Alternate Fuels Utilisation - Dr. A. Lawson

OBJECTIVES To assemble a work plan for phase II of Study of On-Board Hydrogen Generation for Liquid Carriers.

PROGRESS & CURRENT As a follow-up to a previous contract with Engelhard Canada titled "Study of On-Board Hydrogen Generation for Liquid Carriers: Phase I," the Canadian Subcontractor (ORF) was asked to submit a plan for the continuation of this work into its second phase. The ensuing proposal was not acted on because a lower risk route to acquiring the required information was identified as indicated in the alternative work proposal outlined below.

CONTRACT PROOF-OF-CONCEPT FOR THE USE OF DISSOCIATED METHANOL AS A VEHICLE FUEL.

Solar Energy Research Institute (SERI), Fuels Utilization Group - Dr. H. Chum

Subcontractor - Ontario Research Foundation (ORF)

OBJECTIVE To provide quantitative information related to the potential fuel economy advantages of dissociated methanol as a hydrogen carrier for the transportation sector.

PROGRESS A work plan has been proposed which is designed to fill in existing gaps in the technical

understanding of dissociated methanol systems. This proposal builds on past work carried out by SERI as manager of the US Department of Energy, Alcohol Fuels Office R & D Program since 1979. Past work at SERI has included the modification of a 1980 Chevrolet Citation so that it could be operated on fuel from an on-board methanol reforming system. Building on the experience from this first vehicle, and with expertise from many sources, a second improved dissociater and fueling system has been designed and constructed on a Ford Escort vehicle.

The four following major tasks have been defined for a future shared-task contracted activity:

1. Vehicle testing of the SERI dissociated methanol vehicle fueled with liquid methanol and/or dissociated methanol, to be funded by the US Department of Energy.
2. Single cylinder combustion research examining combustion characteristics of various simulated reformed methanol fuel compositions, to be funded from the H&ES program and performed at SERI.
3. Steady-state multicylinder engine dynamometer testing of the SERI dissociated methanol system, funded from the H&ES program and carried out at the Ontario Research Foundation.
4. Refinement and validation of the SERI dissociated methanol system model including predictions of fuel economy comparisons between dissociated methanol and liquid methanol for various power to weight ratio vehicles, funded by the H&ES program and performed at SERI.

CURRENT AND FUTURE NRCC and SERI arrived at a

mutually acceptable program plan and the contract document was ready for signing in November 1984.

CONTRACT EXPERIMENTAL DEVELOPMENT OF AN AMMONIA FUELED ENGINE

Manitoba Research Council, Industrial Technology Centre - Mr. R. Shand
Commenced November 1983
Sub-contractors - Midwest Detroit Diesel & University of Manitoba

OBJECTIVE To experimentally develop an ammonia-fueled engine configuration in which power, efficiency and emission characteristics are optimised. To focus this project, an application relating to a remote location energy system will be considered.

PROGRESS Various options for converting an internal combustion engine to ammonia fueling have been reviewed and vapour induction with spark ignition has been selected as the most promising alternative. An eight-cylinder Detroit Diesel Allison "Fuel Pincher" engine, made available by Midwest Detroit Diesel (General Motors), has been modified to operate on one cylinder. Under Phase II this engine has been converted to use anhydrous ammonia fuel. The conversion required provision for adjustable air/-fuel ratios which was provided by incorporation into the fuel system of LPG components modified to be compatible with ammonia. A further modification was the addition of a high energy MDS spark ignition system. These modifications permitted easy starting on ammonia at laboratory temperature and yielded a

power output when running on ammonia which was equal to that for propane fuel.

Three piston configurations were designed and constructed to permit operation at compression ratios of 14:1, 16:1 and 18:1.

Preliminary designs were drawn for an ammonia dissociator which will produce hydrogen to be used as an additive to enhance cold weather starting. However, from operating experience to date this may not be required in practice because smooth restarting has been demonstrated for coolant temperatures of 10°C.

CURRENT To date thermal efficiencies of up to 48% have been achieved at a compression ratio of 18:1 and there are indications that these levels will be surpassed at increased compression ratios. Residual unburnt ammonia concentrations are very low and from the odour have been estimated at less than 15 parts-per-million.

Testing of the engine is ongoing and includes -

- Optimization of the engine performance with ammonia fuel by varying spark gap size, plug heat range, engine coolant temperature and compression ratio.
- Minimization of fuel consumption.
- Testing fuel additives including hydrogen to assess the impact of a dissociator.
- Developing the means to ensure cold start capability.
- Installation of a conventional automotive three-way catalytic converter to reduce exhaust emissions (in particular ammonia).

- Preparation of a preliminary set of engine modification drawings for assembly of a 100 kW unit operating on ammonia fuel.
- Preparation of a development plan for Phase III.

FUTURE A decision to proceed with Phase III was to be dependent on the results achieved under Phases I and II, as well as the results obtained under the separately contracted systems analysis project. The Phase III plan included conversion of the 8.2 L engine entirely to ammonia (all cylinders). Preliminary marketing was to be addressed.

CONTRACT STUDY OF A MICRO AMMONIA PLANT FOR HYDROGEN ENERGY STORAGE IN REMOTE LOCATIONS

Kilborn Kellogg Ltd. - Dr. N.E. Anderson
Commenced March 1984

OBJECTIVE To assess the feasibility and economics of small scale ammonia production as a component of energy storage with specific application to a remote community relying on a variable or intermittent primary energy source.

PROGRESS Existing proven designs for ammonia plants down to 50 t/d can be considered as a starting point for scaling down to less than 1 t/d which is anticipated as suitable for the requirement.

CURRENT For the purpose of this study a wind powered primary energy source was considered. Design options analyzed included three community loads (500, 4000 and 10,000 MWh/year) with varying average wind speeds, diesel fuel costs and number of wind turbine units.

Developed capital costs included hydrogen plant, nitrogen plant, ammonia plant and utilities for specific ammonia complex sizes of 0.5, 2.0 and 10.0 t/d. Proven designs for ammonia plants down to 50 t/d were used as a starting point for down-scaling.

Due to efficiency losses in the micro-ammonia process, only 17% of excess wind turbine energy can be recovered as diesel fuel savings.

Results of the preliminary financial analysis showed that "under almost all circumstances, the ammonia storage complex does not save enough diesel fuel to cover its maintenance costs, let alone pay back the capital cost".

FUTURE In view of the adverse economics resulting from this study, the approach through down-scaling of existing ammonia plants will be discontinued. Attempts have been made to identify an alternative ammonia production method that is more suited to the production capacities required.

A potential Canadian performer with an innovative new approach to small scale production of ammonia was located and negotiations for a research contract had been commenced.

5.6.2.3 SAFETY AND EMBRITTLEMENT

HYDROGEN SAFETY

Rationale: The direct use of hydrogen as an energy carrier in specific applications is becoming increasingly probable. Future demonstrations and probable applications could bring hydrogen into close contact with the public. It is therefore essential that no aspects of safety should be overlooked. Hydrogen already suffers from a low public confidence due to the inappropriate association with "Hindenberg" and hydrogen bombs so that any accident could provide a considerable set-back to the acceptance of hydrogen in the public domain.

It is necessary to establish a data base on the handling and storage of hydrogen. The data must be analyzed and augmented where necessary with experimental work. In addition it will be necessary to prepare technical information on hydrogen safety and to formulate standards relevant to the safe use of hydrogen in energy applications.

State-of-the-Art: Numerous reports and documents are available which pertain to safety hazards associated with the use of hydrogen in an industrial or laboratory setting but there is a scarcity of information relating to the potential hazards of hydrogen used under circumstances where contact with an inexperienced public could be expected. Regulations and codes are generally of a preventative and restrictive nature and are often non-specific to hydrogen and may have little relevance to the contemplated future energy use.

COMMITTEE HYDROGEN SAFETY

Recommendations were made, under a previous contract on hydrogen safety, for the formation and structure of a National Hydrogen Safety Committee. A Task Group on Hydrogen Safety was convened in May 1983 which led to creation in July 1984 of the Hydrogen Safety Committee, recognized by the National Research Council as a sub-committee to the Advisory Committee on Energy. Elected officers of the committee are:

Dr. D.R. Hay, Hydrogen Industry Council, Chairman

Mr. R.E. Knowlton, Chemetics International Company, Executive Secretary

Mr. J.R.B. Murphy, National Research Council, Administrative Secretary

Activities of the Committee in this past year have included:

- organization of a Workshop on Hydrogen Safety at the Fifth World Hydrogen Energy Conference.
- analysis of the current status of hydrogen safety codes, standards and regulations.
- communications with the hydrogen community,
- discussions on public perceptions of hydrogen safety.

These activities will be detailed in the annual report of the Hydrogen Safety Committee.

CONTRACT HYDROGEN SAFETY COMMITTEE SECRETARIAT.

Chemetics International Limited - Mr. R.E. Knowlton

Commenced July 1984

OBJECTIVE The professional services of Mr. R.E. Knowlton will be retained to provide secretariat services for the Hydrogen Safety Committee.

HYDROGEN EMBRITTLEMENT

Rationale: A recognized safety problem associated with hydrogen arises from hydrogen embrittlement where hydrogen causes a premature degradation in the strength of steels and alloys resulting in sudden catastrophic failure. This effect is not only produced by free hydrogen but can result from environments containing hydrogen sulfide, hydrogen chloride and even water. For small applications this problem can be overcome by judicious selection of materials or component replacement without excessive cost penalty. For large scale hydrogen transmission and handling requirements, low-cost solutions, preferably using commercially available materials, will be essential.

State-of-the-Art: Although the fundamental mechanisms of hydrogen embrittlement of metals have been studied for many years the process remains poorly understood and there is a lack of detailed and reliable information suited to large scale, low cost engineering design requirements.

CONTRACT MATERIALS FOR GASEOUS HYDROGEN CONTAINMENT
Canatom Inc. - Mr. J.K. Riley
Commenced September 1984
Subcontractors - Institute for Hydrogen Systems
- Atomic Energy of Canada - Research Company
- Ontario Research Foundation

OBJECTIVE To ensure the existence in Canada of an engineering and materials data base which will allow the proper choice of materials and associated design parameters for the safe containment of gaseous hydrogen in practical, engineering scale systems.

PROGRESS AND CURRENT The first phase in this activity was aimed at identifying that work which is needed to achieve the stated objective, and was completed in March 1985.

The final report of phase I contains an extensive background of supporting material relating to the basic classification of hydrogen embrittlement phenomena, sub-critical crack growth knowledge and its application and the role of fracture mechanics in materials testing and engineering design. Recommendations for a future work program are derived from a considerable knowledge and experience as presented by persons actively engaged in research related to current industrial applications. The documentation and critical examination of relevant current activities both in Canada and elsewhere are treated under the following four activity areas, detailed in separate appendices:

- Oil, gas and aerospace industries
- Hydrogen embrittlement in CANDU pressure tubes
- Hydrogen damage in the heavy water industry
- Surface transportation, domestic heating and commercial processing.

FUTURE A program for relevant investigative work was to be carried out in coordination with work already progressing in both Canada and elsewhere, in particular with the newly formed Task VII under the International Energy Agency Hydrogen Implementing Agreement.

LIQUID HYDROGEN TANK SAFETY TEST

Rationale: Current technologies for hydrogen storage are compression, solid compound formation (hydrides), liquid compound formation (methanol, ammonia) and liquefaction. Each of these techniques has its own particular advantages and disadvantages. Liquefaction results in the highest gravimetric density possible. It is therefore attractive in transportion applications and numerous demonstration vehicles using liquid hydrogen fuel have appeared in recent years. There are unique safety concerns associated with the storage of liquid hydrogen in vehicles.

State-of-the-Art: Liquid hydrogen has been in laboratory and industrial use for many years. In the USA, bulk shipment of liquid hydrogen is well known through its use by NASA as a rocket fuel. The future possibility of liquid hydrogen being used as a vehicle fuel in close contact with the general public will increase the hazard and safety concerns.

In a previous co-operative project, the Deutsche Forschungs-und Versuchsanstalt fUr Luft-und Raumfahrt (DFVLR), the US Department of Energy, the Los Alamos National Laboratory (LANL) and the New Mexico Energy Institute participated in a joint effort to evaluate and demonstrate a state-of-the-art hydrogen-fueled vehicle with liquid hydrogen on-board storage. The operation of a hydrogen powered passenger automobile was documented during road tests over several months. At the completion of this activity in 1982, the vehicle tank together with other components was donated to the Institute for Hydrogen Systems (IHS) for testing to be carried out by a contract financially supported by the Hydrogen and Energy Storage Program.

CONTRACT VIBRATION TESTING OF AN ON-BOARD LIQUID HYDROGEN DEWAR

Institute for Hydrogen Systems - Dr. Y. Rotenberg
Commenced August 1984

OBJECTIVE The objective of this project is to provide test data which can assist in the design and fabrication of future on-board storage systems; and which will contribute to the development of certification schedules, standards, codes and regulations.

PROGRESS Phase I was comprised of an evaluation of the safety procedures and requirements for the execution of the project, evaluation of relevant reports from LANL and DFVLR, study of vacuum loss and vibration testing procedures, and determination of testing procedures.

CURRENT In Phase II, a test facility consisting of a hydraulic actuator and servo controlled shaker table has been designed and is under construction. This will allow simulation of a variety of vehicle motions related to road and driving conditions. Measurements will be made of heat leakage, pressure build-up and hydrogen boil-off rate. The observed stationary tank base-line characteristics will be compared to those from the tank when subject to controlled vibration under conditions of free venting or pressure build-up as a function of quantity of liquid hydrogen content.

FUTURE At this time there are no plans for continuation beyond phase II; however, the requirements for further work were to be re-assessed as results from this phase become available.

5.6.2.4 FUEL CELLS

Rationale: Fuel cells are capable of directly converting a variety of chemical fuels to electricity without the Carnot efficiency constraints imposed on electrical generation via heat engines. As such they are of direct concern to the Conservation and Alternative Fuel aspects of the Canadian energy program. Since all practical fuel cells actually run on hydrogen, the technical responsibility for the fuel cell R&D falls within the Hydrogen and Energy Storage Program.

Classification and characterisation of fuel cells is complex due to the evolution of a diversity of designs depending on the application area, fuel, structure and materials. Consequently the optimum selection for a specific application and environment is difficult, as is the determination of those developments to be encouraged as having the greatest potential benefit to Canada.

State-of-the-Art: In recent times, mainly due to efforts associated with the American space program, fuel cells have advanced to the point where commercial realization is imminent. Several large American organizations are active in fuel cell research and development including: United Technologies Corp., Energy Research Corp., Engelhard Industries, General Electric and Westinghouse. Recently the United Technologies Corporation has combined efforts with Toshiba Corporation to commercialize fuel cell power plants under the name International Fuel Cells Corporation. Other major activities are at Siemens AG, Brown Boveri and Co. and Varta in West Germany, Elenco (Belgium) and Alsthom (France). Canadian activity is very small by comparison with these major foreign interests. Although there is no significant commercial activity in Canada, a considerable application potential exists.

An activity was evolving under the H&ES program by which a selection of representative foreign fuel cells would be purchased and tested under individually negotiated contracts. The rate of implementation of this program was constrained by the availability of fuel cells, identification of suitable contract performers and funding levels.

A 40kW power unit has been developed by United Technologies with funding from the Gas Research Institute. A program of field tests for 44 units of the same configuration in on-site industrial combined heat and power applications has been commenced with participation of about thirty-one utilities in the USA and Japan. One of these field tests will be carried out in Canada under support from the H&ES program.

Information has been exchanged between Westinghouse and this program with a view to purchasing one of the high temperature Westinghouse ceramic cells for testing.

The mobile application of fuel cells (as compared to stationary application) presents greater technical and economic challenges and will therefore require more extensive research and development. The national fuel cell program will undertake testing and evaluation of existing fuel cells suitable for mobile applications with the first planned acquisition being an alkaline cell developed by Elenco (Belgium). Support for improving existing foreign fuel cell technologies is foreseen together with support for R&D on uniquely Canadian concepts.

CONTRACT FUEL CELL POWER PLANT TESTING PROGRAM

B.C. Hydro - Dr. M.M. Papic
Commenced September 1984

OBJECTIVE To evaluate a 40 kW phosphoric acid fuel

cell purchased from United Technologies International Inc. This will be effected by carrying out field trials for an appropriate Canadian application, and by analysing the potential for similar or related power plants applications in other site specific situations across Canada.

PROGRESS The 40 kW United Technologies phosphoric acid fuel cell power plant was delivered in April 1984 and stored at the Institute for Hydrogen Systems in Toronto prior to being exhibited at the 5th World Hydrogen Energy Conference held in Toronto from July 15 to 19.

Twelve proposals were received in response to a "request for proposal" for testing this fuel cell. The contract was awarded to B.C. Hydro with a work plan including installation of the fuel cell power plant together with sensors, data logging and control equipment in a 40 ft road mobile trailer to provide a mobile fuel cell demonstration unit.

This particular power plant is designed to operate on natural gas which separates the fuel cell's future from the availability of low cost hydrogen derived from water. In this respect, as a mixed gas and electric utility, the selected contractor is considered to be particularly suitable for identification of future applications.

CURRENT At this time the preparation of the trailer assembly has been completed and is ready to be transferred to the B.C. Hydro Surrey Research Centre where the fuel cell will be installed. The "Final Design Specification Report" has been accepted and

the program test will commence at this location with the fuel cell tied in to the electrical and domestic hot water supply systems for the Research Centre. Laboratory tests will be conducted to verify operating characteristics, to determine efficiencies and improve reliability of operation.

FUTURE The test period required for the Gas Research Institute cooperative program will be completed in August 1986 and additional testing by B.C. Hydro is scheduled for completion by April 1987. It is anticipated that an alternative site for further testing under different conditions will have been selected in advance of that date.

CONTRACT DATA AQUISITION AND ANALYSIS ACTIVITIES FOR THE 40-kW FUEL CELL POWER PLANT.

Science Applications Inc. (SAI) - Mr. C. Racine
Commenced October 1984

OBJECTIVE To design, procure and install a standard data aquisition system in the United Technologies 40-kW fuel cell power plant purchased by the H&ES program.

To read and analyse data collected and to report the results to NRC and the operating utility.

PROGRESS To maximize the value of the Gas Research Institute fuel cell field test program it was necessary that accurate and consistent data should be obtained from each test site. SAI is the designated coordinating contractor and is responsible for specifying the data aquisition system and for analysing

all data collected. The H&ES program will take advantage of this fully developed system of data collection and analysis for the above mentioned fuel cell study.

CURRENT System design and specification and purchase, test and delivery are essentially complete. Electrical and thermal system instrumentation interfaces and sensors will be installed by B.C. Hydro as soon as the fuel cell is located at the test site. Start-up and training will follow.

FUTURE The original contract included data collection and analysis at the B.C. Hydro test site and at a second site as yet unspecified; however, under the current contract modification this activity will be discontinued in March 1986.

"IN HOUSE" PROGRAM SOLID ELECTROLYTE FUEL CELL DEVELOPMENT

CANMET (EMR) - Dr. T.A. Wheat
Commenced April 1982
Parts of this work are performed under contract by Queen's University (Dr. M. Sayer) and McMaster University (Dr. P. Nicholson).

OBJECTIVE The objective of this program is to develop solid electrolyte hydrogen fuel cells. The work will include development of three-dimensional H_3O^+ conducting ceramic electrolytes, development of necessary hydrogen permeable electrodes and design of cells with optimized stacking and thermal management potential. This will be followed by transfer of the electrolyte fabrication and electrode deposition techniques to an industry based pilot plant.

PROGRESS & CURRENT A production method for hydronium-β-alumina precursor material based on inexpensive commercially available raw materials and

a conventional spray-drying technique has been developed to replace the costly freeze-dry process used in earlier production of this material at CANMET and McMaster University. The resulting precursor materials have a fraction of the undesirable beta component of 0.17 compared to a maximum acceptable value of 0.37. Ion exchanging these materials continues to be the most critical step. The yield of partially exchanged material is unacceptably low, and fully exchanged material has not been prepared without fracture. Strength of precursor material is thought to be a consequence of the relatively coarse raw material used, and the spray-drying process. Attempts to use a finer raw material failed to maintain the fraction of undesirable beta alumina at less than 0.37. Control experiments with high grade materials suggest a strong correlation between the crystallite size of the raw material and its magnesium oxide content which is commonly incorporated to control grain growth in alpha-alumina.

Previously reported work on three-dimensional conductors has continued. Zirpsios had previously been ion exchanged to the hydronium form and demonstrated in a simple hydrogen/air cell. Further examination has been made of some of the processing parameters involved in preparing the precurser sintered materials and their relationship to the ion-exchange survival rate. Discs of 2.5 cm diameter have been produced for use in preliminary electrode studies. Preparation of CASICON and YASICON by conventional ceramic processing had previously been demonstrated and a patent has been filed on behalf of the Crown. Further refinements have led to the demonstration of the performance of these materials in a room

temperature electrolyser. Because of their well-known performance and ease of application, platinium electrodes have been used essentially as a standard to establish behaviour of the electrolytes. However, at the elevated temperature of operation it is expected that good electrode kinetics will be obtainable without the use of noble metal or alloy catalysts, and efforts are being made to characterize and develop suitable electrode systems.

An earlier survey of candidate electrode materials suggested Ni, $NiCoO_3$, $LaNi_5$ and $LaCoO_3$ and some of the TiO_2-based perovskites. Development of deposition processes has continued, and a strongly bonded layer of $NiCoO_3$ has been produced by careful decomposition of aqueous mixed nitrates followed by a hydrogen anneal. Efforts are continuing to identify those process parameters that significantly influence deposit conductivity, and to extend this process to other compositions. Preliminary examination of plasma-sprayed coatings has also been made.

An automated system to characterize electrodes as a function of temperature and partial pressure in each half cell of a laboratory scale working fuel cell is being assembled by CANMET. This should be in operation for polarization studies by mid-85.

Electrodes and electrolytes are most commonly characterized by electrochemical techniques that are dependant on the assumption of various models. Although concentration polarization may be readily determined electrically, a direct and independent method of measuring electrode morphology, porosity and tortuosity is desirable as these quantities are

extremely sensitive to parameters of prior processing. A study has been initiated at Ontario Research Foundation to identify appropriate non-electrical techniques that can be used to physically characterize an electrode and the three phase line, and which will minimize dependence on model assumptions.

FUTURE Cell designs will be developed using evolving estimates of electrode and electrolyte performance. Throughout this project, attention will be directed to the solution of potential problems associated with industrial production.

CONTRACT LOW COST SOLID POLYMER ELECTROLYTE (SPE) FUEL CELLS

Ballard Technologies Corp. - Mr. P. Howard -
Commenced November 1983
Contract management - Defence Research Est. Ottawa (DREO) - Dr. C.L. Gardner

OBJECTIVE To develop a low cost SPE fuel cell technology capable of meeting a number of military and civilian applications. The work will concentrate on the development of an SPE technology that is compatible with the use of impure hydrogen produced by reforming a liquid fuel such as methanol.

PROGRESS Effective methods have been developed for the fabrication of carbon based electrodes and cell assemblies. Single cells can now be built with an area of 31 cm^2 and capable of operating at 200 mA/cm^2 at 60°C using hydrogen and air at one atmosphere. No decrease in performance has been observed after operation times exceeding 500 h. The results to date indicate that the performance

goals set at the beginning of the contract will be met.

Work has been initiated in the areas of carbon-monoxide-tolerant catalysts, cell design and materials selection.

FUTURE Work will be concentrated on fuel cell stack design, the development of carbon monoxide tolerant catalysts and the reduction of electrode catalyst loadings.

Three prototype fuel cells (72 W) will be delivered by March 1986.

5.6.2.5 ENGINES AND SUB-SYSTEMS

Rationale: Although fuel cells are often claimed to be the ultimate energy conversion device for hydrogen, they are not developed to the extent where any substantial market penetration can be foreseen at present. It is expected that the direct energy use of hydrogen as a fuel for motive power, if it occurs at all, will be initially through the use of internal combustion engines.

Because of the unique burning characteristics of hydrogen (e.g., high flame velocity and wide flammability range) an engine designed for hydrogen fuel is expected to show a considerably improved operating efficiency as compared to existing hydrocarbon fueled engines.

State-of-the-Art: There are numerous examples, from many countries and over many years, of conventional engines being modified to accept hydrogen fuel. The burning characteristics of hydrogen have been recorded using research engines. Although much of this previous work is fragmentary and incomplete it serves to indicate possible performance levels that might be expected from hydrogen engines, it has indicated some of the research and development requirements which must be addressed and has narrowed the technical scope of research directions worthy of further effort.

For increased efficiency, hydrogen fueled engines require compression ratios greater than those of conventional gasoline fueled engines. Precautions must be taken to eliminate the debilitating effects of the low ignition energy of hydrogen which causes erratic operation. It is suggested that direct injection fueling is one method of overcoming this latter problem and at the same time allows the engine to achieve power

outputs equivalent to those of current diesel engines of the same displacement. This has recently been demonstrated in Japanese experiments.

CONTRACT EXPERIMENTAL INVESTIGATION OF A DIRECT-INJECTION HYDROGEN-FUELED DIESEL ENGINE WITH IGNITION ASSIST

University of Toronto - Dr. J.S. Wallace
Commenced January 1983

OBJECTIVE To establish experimentally the performance levels for hydrogen-fueled operation using a single-cylinder direct-injection diesel engine, with high swirl and either glow-plug or spark ignition; and to determine the NO_x emissions.

PROGRESS A Lister diesel engine was instrumented and tested for baseline operation with diesel oil. Brake specific fuel consumption and emission characteristics were mapped for a range of engine speeds. The advantages and disadvantages of previously used design concepts for the critical hydrogen fuel injector, were assessed, and a hydraulically actuated injector using a modified diesel fuel injector pump driven by the engine, was selected for further design and construction.

CONSTRUCTION Design modifications indicated from engine testing of the injector are being carried out. Test data will be recorded and analyzed for operation with hydrogen using glow plug assisted ignition. A second cylinder head will be modified for spark plug ignition and test data will be recorded and analyzed.

FUTURE Although no follow-on has been defined it was expected that the results of this project would lead to further development. The work was to be coordinated with parallel activities within the Hydrogen and Energy Storage Program, such as the work on liquid carriers (CH_3OH) which required information on the burning characteristics of CO/H_2 mixtures. This latter topic has been addressed at the University of Toronto in a program funded by the Ontario Ministry of Transportation and Communications.

"IN HOUSE" PROGRAM EXPERIMENTAL INVESTIGATION OF DIRECT-INJECTION HYDROGEN-FUELED ENGINE WITH COMPRESSION IGNITION

National Research Council (Fuels and Lubricants Laboratory) - F.R. Billingham
Commenced April 1983

OBJECTIVE To design, develop and test optimized methods of injection of hydrogen at the highest achievable density so as to obtain maximum penetration and dispersion and thereby aid controlled homogeneous combustion. Combustion and auto-ignition will be evaluated with air and noble gas mixture using a single-cylinder research engine. A noble gas working fluid (as compared to air) produces higher pressure increase for the same compression ratio. Such an engine has of course to operate on a closed cycle and hydrogen fueling is ideal because of the relative ease of condensing water in the recycle circuit.

PROGRESS The program is divided into three phases.

Phase I. Design and development of the injector/pump assembly. The assembly will be tested with liquid nitrogen and then qualified with liquid hydrogen. Phase I is currently nearing completion.

Phase II. Integration of injector/pump assembly to the test engine. Evaluation of combustion and auto-ignition with air.

Phase III. Evaluation of noble gas mixture auto-ignition.

CURRENT By a reiterative process of design, modification and testing the injector has been developed to provide suitable injection periods throughout the required engine speed range. Design developments have been incorporated into a final form for the injector assembly and the extensive engine alterations required to accommodate the injector and camshaft assemblies have commenced.

FUTURE No follow-on was defined but it was expected that the results of this project would lead to further development. The work was to be coordinated with parallel activities within the Hydrogen and Energy Storage Program.

CONTRACT GAS TURBINE HYDROGEN COMBUSTION RESEARCH

Pratt & Whitney Aircraft of Canada Limited -
Dr. P. Sampath

Commenced January 1983

OBJECTIVE To evaluate combustion characteristics of hydrogen over a range of conditions which simulate the operation of small gas turbine engines. The influence of fuel injector design on the mixing and combustion characteristics of hydrogen will be examined. The project will provide data and recommendations concerning hydrogen combustion with conventional burner designs and will generate a data base for more advanced design concepts.

PROGRESS Performance of hydrogen has been evaluated in a single can burner system. To facilitate comparisons these initial tests were carried out in

a burner identical in configuration to one used for evaluating several broadened specifications and alternative fuels under an existing joint American/ Canadian program. The hydrogen tests were followed by similar tests using natural gas. (The latter are not funded by the Hydrogen and Energy Storage Program.)

The work was divided into two consecutive phases.

Phase I. Test planning and instrumentation set-up was carried out with emphasis placed on the effects of the properties of hydrogen on the performance of different types of fuel nozzles/injectors, combustor performance effects on the engine hot section, and exhaust pollutant emissions.

Phase II. Tests and analyses were conducted for a range of fuel-air ratios, inlet air pressures and temperatures, and combustor loadings. The major parameters of interest were:

- metal temperatures
- flame characteristics
- combustion efficiency
- stability characteristics
- emmissions
- combustor exit temperature distribution.

The tests and analyses have indicated promising directions for combuster design development that would exploit the unique combustion characteristics of hydrogen.

CURRENT Ignition performance and operating

efficiency indicate excellent mixing and combustion characteristics of hydrogen with the possibility of achieving adequate performance using much smaller combusters.

Nitric oxide emissions from hydrogen fueling were much higher than those from either Jet Al or natural gas over the whole power spectrum. However, it is expected that combusters designed for lower residence time and reduced reaction zone temperature will achieve required NO_x reduction without performance penalty.

Localized regions of high combustion wall temperatures occur when liquid fuel combusters are fueled with hydrogen. This points to durability as an important consideration in designing for hydrogen.

FUTURE The final report (June 1984) recommended support for the design and test of a combustion system which would exploit the combustion characteristics of hydrogen as identified in the completed phases I and II. For this new phase a modified PT6A type engine was suggested.

A further recommendation was to evaluate the effect of liquid hydrogen fueling on combustion system design and construction.

5.6.2.6 SYSTEMS ANALYSIS

Rationale: Although the lowest cost hydrogen in Canada is currently derived from the steam reforming of natural gas, it is expected that for some locations this situation will change in favour of electrolytic hydrogen from nuclear, hydraulic or other inexhaustible energy sources.

The availability of competitive non-fossil derived hydrogen will allow development of new end-uses particularly in applications where advantages arise from the special aspects of hydrogen energy technology.

CONTRACT NEW USES OF HYDROGEN IN CANADIAN ENERGY SYSTEMS

Chemetics International Limited - Mr. R.E. Knowlton
Commenced January 1984

Sub-contractors - B.C. Hydro and Power Authority
- Urban Transportation Development Corporation Ltd.
- Canocean Resources Ltd.
- Jarvis Clark Co. Ltd.
- Petrocarbon Developments Ltd.
- Hydrogen Industries Council.

OBJECTIVE To identify, document and analyse possible new uses of hydrogen in specific Canadian applications

PROGRESS & CURRENT This activity is directed toward the identification of "niches" where special aspects of hydrogen energy technology, such as clean burning and absence of hydrocarbon pollution, can be

advantageously exploited in the near future. The study is restricted to those applications which are considered to have reasonable prospects for technological inplementation, reasonable implementation costs and are free from regulatory or institutional impediments.

In the first stage ideas were generated from lists of the special characteristics of hydrogen and through interchange between the varied subcontractors. In each case sufficient information was sought to include the idea in a process for further development or to reject it. From the developed ideas a portfolio of specific hydrogen applications opportunities will be subject to a peer review, and the surviving ideas will be comprehensively documented with identification made of both technical and non-technical constraints to implementation. Advantage was taken of the 5th World Hydrogen Energy Conference, which was coincidentally in Toronto in 1984, as an environment for stimulation of ideas. It was anticipatd that a large diversity of potential applications would need to be screened by the various levels of selection process. To enable this study to be carried out, Chemetics assembled a wide range of subcontractors with user-oriented specialist knowledge in such areas as submarines, mine vehicles, aircraft, urban transportation, gas and electric utilities and emergency power.

FUTURE The work carried out under this contract was to provide input with respect to the content and priorities of future activities to be included under the Utilization Sub-section of the Hydrogen and Energy Storage Program. None of the identified

applications were necessarily to be implemented, and any continuation was to be dependent on the results of "in-house" appraisal and priorizing.

5.6.3 ENERGY STORAGE

Energy storage and conversion techniques are relevant to the interfacing of new energy sources to existing and future demands. Our present heavy dependence on oil as a primary energy source has led us to take for granted many of the remarkable features of the energy system we have constructed for using oil. The occurrence of oil in highly concentrated deposits is in itself a major economic benefit albeit clouded at times by political considerations. A wide range of fuels are manufactured from oil by simple and inexpensive processes. These fuels have enormous volumetric and gravimetric energy densities and are readily transported and stored. However, oil will not last forever and we must recognize that no other single energy source or manufactured fuel commodity has such attractive features.

Displacement of oil will require the conversion of alternative energy sources to forms with acceptable characteristics for various specific applications.

A large fraction of our future energy will appear in the form of electricity which is difficult to store and will require economical and efficient conversion to a more readily stored form.

The use of storage to interface between variable rates of production and demand, and to smooth energy flows, makes a major contribution to energy conservation by allowing energy from periods of excess availability to be utilized during subsequent periods of excess demand. This procedure is relevant to electric utilities now and will grow in importance when intermittent and dispersed sources such as wind, solar and small scale hydro are developed.

The most demanding application of energy storage systems is in transportation. Heavy reliance is placed on liquid fuels for this application because of their high volumetric and gravimetric energy storage density and their ease of handling.

Energy storage techniques are frequently highly specific to the form of the source energy and the energy end-use. In such cases, storage is most successfully studied as an integral part of the complete energy system. An example of this is low temperature heat storage associated with solar energy utilization which does not appear as part of the Energy Storage program but comes under the mandate of the Solar Energy Program.

5.6.3.1 ELECTROCHEMICAL STORAGE

HIGH TEMPERATURE BATTERIES (Li/FeS)

Rationale: Canada does not yet have an indigenous battery manufacturing industry and is reliant on large branch plants of well-established international battery manufacturers to supply its needs. As a consequence of this situation, there is a limited scope for benefits to Canada from the funding of R and D in conventional battery technology.

The advanced battery systems required to meet battery needs of the future are at a much lower level of development. There is therefore a possible point of entry for the eventual establishment of a Canadian battery manufacturing capability.

To approach a significant level of effort within the confines of limited available resources it has become necessary to concentrate attention on a single system whilst maintaining an awareness only of other alternatives being developed elsewhere. The system of choice is molten salt lithium/sulfur which has subsequently evolved into lithium-aluminum alloy/molten salt/iron sulfide (commonly referred to as lithium-iron sulfide or Li/FeS). Major considerations favouring this choice are the comparative safety, potentially high specific energy and suitability for vehicular applications.

It should be pointed out that other funding sources are supporting the development in Canada of ambient temperature lithium rechargable batteries (Moli Energy, Ballard Research, both of Vancouver).

State-of-the-Art: Research and development activities on various advanced battery systems are currently being supported by

all major countries, battery manufacturers and other industrial and manufacturing organizations with interests in future battery applications such as electric vehicles, load levelling and military applications. No clear winner is apparent at this time. The lead/acid battery continues to dominate the field except in a few limited applications (aircraft, space, etc.). Two advanced high temperature batteries which are attracting considerable interest are lithium-iron sulfide and sodium-sulfur.

The US effort on the LiAl/FeS battery is being co-ordinated by Argonne National Laboratory and EPRI with various development contracts let out to groups including Gould Inc., General Motors and Eagle Picher. Activities are also known at Varta (Germany) and the Korean Institute of Science and Technology. Major development programs are also underway in Japan and in the UK (British Admiralty). Recently the British program has stepped up its efforts and has let out a contract to SAFT for further industrial development. Major problem areas include capacity decline, electrode swelling and development of a low cost, low resistance separator.

The sodium-sulfur system is being developed in USA, UK, France, Germany and Japan. Its problem areas include mechanical reliability, thermal shock resistance, safety and cost of the β-alumina solid electrolyte.

The Canadian effort is for developing LiAl/FeS batteries with boron nitride (BN) separators. It is well known that BN separators produce the best cells; however, there is no known source of BN felt. It is anticipated that by developing a low cost BN separator technology and a BN based LiAl/FeS battery, the Canadian program will develop superior technology over the other national efforts. In order to implement this strategy, two parallel programs continue to be operated:

1. Lithium/Metal Sulphide Bicell Fabrication
2. High Temperature Battery Separator Development

Successful outcome of these two contracts will lead into the final stage of the program, which is development of the integrated LiAl/FeS battery comprised of bicells with BN separators.

CONTRACT LITHIUM/METAL SULFIDE BICELL FABRICATION

The Electrofuel Manufacturing Co., Toronto -
Dr. S. DasGupta
Commenced February 1983

OBJECTIVE To optimise LiAl/molten salt/FeS bicells using designs and fabrication techniques which are suitable for commercial production.

PROGRESS The first phase establishment of engineering specifications for the cells, analysis of manufacturing technology options, target cost optimizations, and identification of component sourcing has been satisfactorily completed. Phase II of the project is progressing satisfactorily having produced excellent baseline bicells.

Various improvements have been made in the technology including development of internal electrode particle retainers, low cost method of producing electrodes, ability to use technical grade salt, new sealing mechanism, improved electrical feed-through design, method of producing LiAl battery grade alloy, dimensionally stable cells and electrodes.

CURRENT All major tooling and facilities are

available to manufacture the cells. Fifteen baseline cells have been built and a number of them have undergone post-mortem analysis for input to various design iterations.

Numerous improvements have been made to both the bicell and component design and also to the development of production technology. The baseline bicells are also being used in sub-programs for component and materials selection and processing and manufacturing techniques.

Both performance and costs have been major targets in this bicell development program and major cell cost reductions have been achieved in both raw material selection and in production methods. Various cell optimization works have been carried out and completed.

A prototype cell fabrication facility has been built and the design, engineering specifications and manufacturing options have been fixed.

FUTURE A test production run of 40 bicells is underway and it is expected that 100 cells will be produced in this program. These will include groups of baseline cells as well as certain advanced designs.

With successful completion of the current work the logical next step would be the design, development and testing of a prototype battery based on these cells.

IN-HOUSE MOLTEN SALT SECONDARY BATTERY CELL EVALUATION

Defence Research Establishment Ottawa - W. Adams
Commenced April 1980

OBJECTIVE Testing and evaluation of engineering scale prototype high temperature Li/FeS cells including long-term charge and discharge cycling at a variety of rates and temperatures and assessment of failure mechanisms by physical and chemical methods.

PROGRESS & CURRENT Under this activity engineering prototype Li/FeS cells resulting from the previous research program at Hydro Quebec and more recently with Electrofuel Manufacturing Co. have been tested at the Defence Research Establishment Ottawa (DREO). Cells obtained by DREO from other sources have also been tested for comparative purposes. This testing activity is vital to the battery program in providing the necessary feed-back to indicate areas of research requiring further attention. Expansion of the facility to provide a ten cell computer controlled cycling and testing capability is almost complete and will accommodate the testing of cells resulting from the lithium/metal-sulfide bicell fabrication contract. At the beginning of fiscal year 1984/85 salaries for the personnel operating this facility were transferred to the contract managed by Electrofuel Manufacturing Co.

FUTURE It was proposed that expansion of the battery test equipment at DREO would continue and eventually be relocated to provide the nucleus of a facility for battery testing which would provide an interpretive link between manufacturer and user interests in the area of new and/or advanced batteries. A number of options are being explored which will allow the continuation of this activity.

BORON NITRIDE SEPARATORS

Rationale: Boron nitride is an electrically insulating material with high corrosion resistance that can be fabricated as a felt. This material has proven capability as a separator having been utilized in the best high temperature Li/FeS batteries built to date.

State-of-the-Art: In 1982, the only known commercial manufacturer of boron nitride felts (USA) ceased production. It had earlier been decided by the Hydrogen and Energy Storage program that both the quality and cost of available boron nitride material were capable of considerable improvement through a modest research effort. In spite of its high cost, boron nitride is the first choice as a separator material for high temperature Li/FeS batteries. The future competitiveness of the Li/FeS battery selected for development under the Canadian program will be greatly enhanced by development of an economic source of high quality boron nitride felts.

CONTRACT HIGH TEMPERATURE BATTERY SEPARATOR DEVELOPMENT - Phase III

The Electrofuel Manufacturing Company -
Dr. S. Das Gupta
Commenced November 1984

OBJECTIVE To develop a boron nitride felt separator pilot plant based on the research and experimental results obtained from Phases I and II. This will prove the laboratory scale results and generate a BN pilot plant facility capable of producing sufficient felt to support the Bicell Fabrication Program and anticipated subsequent battery development programs.

PROGRESS Phases I and II of the program were carried out technically at Ontario Research Foundation (Dr. M.K. Murthy) under the general direction of Blue Mountain Pottery Ltd. (Mr. R. Miller). Under Phase III an engineering design study for the pilot plant was completed and the design report submitted. Various unit operations were scaled up, the plant was constructed and the first batch of boron nitride felt was produced by mid-March 1985.

CURRENT The pilot plant felt product is being characterized with respect to materials made in the laboratory as well as by comparison with the old Carborundum process product. The separator material is being proved by both external characterization and by in situ cell testing.

Data being generated on the kinetics of the fibre nitridation reaction will lead to further optimization of the unit processes. The cost of the boron nitride separator product is continually monitored to ensure that targetted price objectives are being met. Materials of different fibre diameter have been made to investigate the possibility of a low cost route to making the fibres easily wettable by the molten salt. The pilot plant is operating successfully and is now the only source of boron nitride fibres and felts.

FUTURE Remaining work under this contract will concentrate on further optimization of unit processes and consequent modifications to the plant.

From what was basically an electrochemical battery development program a unique ceramic processing facility is being created with exciting potential for spin-off activities outside the mandate of the Hydrogen and Energy Storage Program.

ALUMINIUM AIR BATTERIES

State-of-the-Art Although most commonly referred to as an aluminum/air battery this device in operation has the essential character of a fuel cell. Physically it consists of an aluminium metal anode, a saline or alkaline electrolyte and an oxygen cathode supplied from atmospheric air. During discharge the aluminum electrode is consumed and recharging is carried out by mechanical replacement of the anode. Electrolyte circulation and management is necessary to collect the chemical reaction products which are then externally recycled. The concept of mechanical recharge gives characteristics that are considerably different to those for other batteries and as a vehicle power source this results in a substantial increase in range as compared to conventionally powered E.V.s. In general the use of a saline electrolyte restricts cells to low power density, but the alternative alkaline electrolyte produces a cell with both high power and high energy albeit at the expense of an increased operating temperature (60°C). Currently the main centre for aluminum/air battery research activity is in the USA at Lawrence Livermore Laboratories (Cooper) and at Lockheed Missiles and Space Co. (Littauer).

CONTRACT THE ALCAN ELECTRIC VEHICLE PROJECT

Alcan International Ltd. - Dr. N.P. Fitzpatrick.
Program management is the responsibility of Transportation Development Centre (Mr. J. Morgan).
Funding is shared between Alcan, TDC and NRC.

OBJECTIVE Evaluation of the potential role of Al/air batteries as energy storage for road vehicles. To produce an electric vehicle with improved range and performance by the development of a battery/-battery hybrid power supply module consisting of an aluminum/air cell and conventional batteries.

PROGRESS Alcan has been actively engaged in aspects of this system, which relate to aluminum alloys, since 1981. A past difficulty of this system was the high hydrogen production at the anode for cells designed to produce a high output voltage. This occurrence was reduced by replacing the anode material with an appropriate aluminum alloy. Another major impediment was the air cathodes (also used in other battery and non-battery applications) which required costly platinum catalysts. Operating cathodes with reduced quantities of cathode material, or less costly materials, have considerably reduced this problem.

CURRENT A listing of activities and considerations under the contract work statement includes -

- Selection of vehicle
- Analysis of battery requirements and determination of the optimum ratio of aluminum/air to the other battery component.
- Electrolyte management sub-system.
- Thermal management.
- Electrolyte, anode and cathode specification.
- Gas control system.
- Design & Test of separate components.
- Assembly into vehicle for testing on dynamometer and track.

FUTURE This program of practical development and testing will produce information of high reliability which is necessary for assessment of the aluminum/air cell in this hybrid mode, and also by extrapolation in other modes or applications. Possible battery and system weaknesses will be exposed and the requirement for future research and development will be defined.

5.6.3.2 VEHICLE BATTERY AND SUB-SYSTEMS

Rationale: Over fifty percent of oil used in Canada is required for transportation purposes. The use of battery powered vehicles is a direct method of replacing depletable oil based fuels with increasingly available electric energy. The problems and opportunities for introducing electric vehicles are not confined to the development of suitable high density batteries but also includes development of other electric vehicle components by which the complete vehicle system and operation can be implemented and optimized. Although Canada has comparatively low cost electricity, this advantage is off-set, where E.V.'s are concerned, by added difficulties and costs associated with an extreme winter climate.

CONTRIBUTION ELECTRIC VEHICLE RESEARCH

EMR (Transportation Energy Division)/Ontario Centre for Automotive Parts Technology - G.B. Maund.

OBJECTIVE To carry out a program of targeted development, application, and testing of advanced vehicle designs from which the opportunities of Canadian production may be assessed.

PROGRESS & CURRENT Following active participation in the Ontario Task Force on Electric vehicles, the Transport Energy Division entered into a contribution agreement with the Ontario Centre for Automotive Parts Technology to test an advanced electric vehicle drive and control system with lead-acid and sodium-sulfur batteries under Canadian conditions.

The project requires conversion of three Chrysler T115 vans to electric propulsion using a fully developed drive control system designed and produced by Brown Boverie Cie of Heidelberg, Germany. Vehicle conversion is scheduled for late summer and will be followed by periodic laboratory reference tests during a two year in-service test period. The tests will commence with lead-acid batteries as a basic reference, to be followed with tests on prototype high energy density sodium-sulfur batteries developed by Brown Boveri Cie. The objective is to fully appraise the Canadian service performance of the advanced battery system with the electric drive control which incorporates an energy regeneration feature for charging the batteries when braking.

The test results will be representative of future electric vehicles powered by high energy density batteries. In addition to on-road performance data, the tests will determine in-use electrodynamic fuel efficiencies, charging conditions and load requirements on domestic electric supplies.

Preliminary operating, servicing and battery life information will provide insight into the viability of these vehicles in urban delivery service and their prospects for private automobile use, which is of interest to the Canadian automotive parts industry.

FUTURE Results from this project will be used as a guide to electric vehicle assessment and future research and development requirements.

CONTRACT ELECTRIC VEHICLES

Transport Canada - Dr. W.J. Johnson and Mr. J. Morgan
Commenced April 1983

Transport Canada is directing a program of industrial contracts relating to electric vehicle sub-systems and components. This is a continuation of an existing program and includes activities on the development and evaluation of improved chargers for electric vehicles batteries and the development and assessment of continuously variable transmissions for electric vehicles.

The improved charger has been under development by A.C. Statpower (Vancouver) and although comparable with the best systems available the market is uncertain due to a tendancy to incorporate chargers into overall vehicle electric control systems.

The continuously variable transmission of Kerrtrain Systems Ltd. (Kingston) is of interest to the auto industry for application in conventional rather than electrical vehicles.

CONTRACT ANALYSIS OF SUBSYSTEM R&D FOR THE FUTURE NON-HYDROCARBON SYSTEMS FOR VEHICLES

Davis Engineering Ltd. - Mr. A. Bosik
Commenced March 1984
Subcontracts to Booz-Allen Hamilton and Canadian Institute for Guided Ground Transportation

OBJECTIVE To determine the vehicle sub-system research and development needs for non-hydrocarbon fuel storage systems which are potentially suitable for vehicles in the Canadian context and 1990 to 2000 time frame. To develop a means for ranking such needs in order of importance.

PROGRESS A literature and industry survey has identified the following five non-hydrocarbon system categories:

- electrochemical storage - examples are batteries and fuel cells.
- hydrogen storage systems.
- mechanical storage - in the near term consisting of flywheel, hydraulic accumulator or compressed air systems.
- thermal storage - in conjunction with external combustion stirling engines. This system was considered to be beyond the year 2000 time-frame.
- hybrid systems - these are generally comprised of a primary power unit and a power levelling storage unit.

Associated sub-system R & D requirements were identified together with technical barriers to these requirements.

Major market segments were defined, and, based upon appropriate operation parameters, a representative vehicle for these segments was characterized in order to develop realistic application scenarios.

Market segments and vehicle systems were concatenated and eliminations carried out on the basis of engineering feasibility and/or practicality, this was followed by further eliminations where inadequate competitiveness with the base-case hydrocarbon fueled system was predicted. The assessment of economics and competitiveness included considerations of fuel availability and refuel capability. Canadian needs

and capabilities were incorporated into the system requirements, in particular, those arising from climate and demography.

A survey of involved institutions was carried out to determine Canadian capabilities and to assess their current programs within the context of world activities.

CURRENT A matrix comparison scheme has been developed by which the identified R & D requirements are ranked. The sensitivity of the top ranking R & D is analyzed with respect to the basic assumptions used in developing the ranking scheme.

Necessary goals of future research include a significant increase in system competitiveness and achievement within the time-frame 1990-2010. In addition, to justify federal involvement there must currently be inadequate effort addressing the problem area, and a low probability of industrial activity without government incentive.

Other desirable factors in the proposed R & D activities includes involvement of Canadian capabilities, markets or special natural resources, increased system competitiveness, mobilization of electric power, R & D commonalities, potential for joint effort either between industry and government or internationally and improved cost, safety and performance.

The final report is organized into the following six volumes plus an executive summary.

Volume I: Overview

Volume II:	Non-Hydrocarbon system Vehicle Application Scenarios
Volume III:	Non-Hydrocarbon system Life Cycle Costs
Volume IV:	Non-Hydrocarbon Subsystem Technical Barriers, R & D Requirements and Development Costs
Volume V:	Resource Allocation Methodology
Volume VI:	Flywheel Implementation Plan

FUTURE Research and development evaluation by the methods developed under this contract were to provide input for establishing a program of future work in vehicle sub-system research and development and for evaluating new proposals.

5.6.3.3 MECHANICAL STORAGE

FLYWHEELS

Rationale: The variation of power requirements over the driving cycle of a vehicle is commonly accommodated by employing an engine with power output far in excess of the requirement for average operation. This leads to reduced overall efficiency. Flywheels have potential as low cost energy storage for short periods with capabilities for delivering high power densities. Performance equivalent to a regular internal combustion engine with high overall efficiency can be achieved with a hybrid system comprised of a flywheel and low power source such as fuel cell, battery or small internal combustion engine. The flywheel is a convenient means by which deceleration energies can be recovered and applied to acceleration requirements. A significant potential for flywheel deployment exists in stationary applications as well as transportation systems.

State-of-the-Art: A study into the Development of Flywheel Energy Storage Technology for Canadian Transportation Applications was completed by the Urban Transportation Development Corporation in March 1977. Several centres of flywheel activity supporting various design concepts were located (none Canadian) but none hold a dominant command of the field.

Canada has access to the USA federal activities through an exchange agreement with its lead agency, the Lawrence Livermore Laboratories (LLL). Evaluation of high performance composite flywheels is carried out at the Oak Ridge Flywheel Evaluation Lab. under a subcontract from LLL. In 1980, evaluations were carried out at this facility on prototypes built by Garrett-AiResearch, William M. Brobeck & Associates, Hercules Aerospace

and Rockwell-Rocketdyne (all under contract to Sandia National Laboratories), one built by LLL and one by General Electric. The predominant design limitations appeared as instabilities at high speed resulting from problems with the attachment of the central shaft to the heavy rim.

Japanese work under the Moonlight project is studying a flywheel-Stirling hybrid vehicle, and there are European flywheel activities at Aerospatiale (France); Fiat Research Centre (Italy); Volvo (Sweden); M.A.N. (Germany); ECN Netherlands Research Foundation (The Netherlands) and British Petroleum Co. England).

CONTRACT FLYWHEEL ROTORS - DESIGNS, FABRICATION TECHNIQUES AND MATERIALS PERFORMANCE TESTING

University of Ottawa - Dr. R.C. Flanagan - Commenced June 1980

OBJECTIVE To conduct a study to select, fabricate and test non-isotropic materials for flywheels. Using the acquired data base to select an optimum design and then construct and test a 1 kWh flywheel.

PROGRESS An extensive data base of design concepts, materials characteristics, performance and construction techniques has been assembled and used to reduce the selection of potential candidates for a fibre composite flywheel design. Analysis (rotor stress distribution, etc.) has been made of all rotor designs reported in the literature. Key material and design concepts have been identified and the data base extended with results from the fabrication and testing of materials and proof of concept specimens. Under previous contracts the fabrication

facility was expanded from proof-of-concept reduced sizes to full size rims. Results from testing provide continued updating of the data base, and the later results have been measured on test samples taken from full size components.

Manufacturing and assembly procedures are considered as input to the design selection process. Parallel work separately funded by the Natural Sciences and Engineering Research Council has developed the hub design and attachment to a level that is compatible with the characteristics and capabilities of the rotors.

Within the constraints of a 1 kWH useable energy suitable for automotive vehicle application the number of most promising designs has been reduced to four from a field of fifty six. These four are of a multi-material ring structure and are superior to any other known designs. It must be emphasized that the constraints associated with the road vehicle application are very demanding and that the selected designs are subject to these restraints, for example, the designed-infailure sequence of the selected rotor designs facilitates care of containment and safety, while the thick ring design lends itself to mass production.

CURRENT The four selected rotor designs have been finalized and are in the process of manufacture and assembly. A dynamic test facility with computer controlled cycling capability and temperature monitoring has been commissioned in readiness for the rotor testing.

FUTURE It has been recommended that a full scale test bed set-up should precede vehicle implementation as it presents the simplest means to provide the control and monitoring required to identify any remaining deficiencies.

An appropriate industrial partner who can carry this work into commercialization remains to be identified.

5.6.3.4 THERMAL STORAGE

Rationale: Domestic and commercial space heating represents the most immediate high impact area for conversion from oil. Displacement of oil by electricity in this application can result in an increase in peak electricity demand with a consequent requirement for costly, low-load factor, generation capacity. The concept of load levelling allows the displacement of demand peaks by storing energy produced in off-peak periods for subsequent use in satisfying peak requirements. Such storage can be either central or dispersed, and in the latter case there is an added advantage that peaking in the distribution system can also be reduced.

State-of-the-Art: Of the many options for thermal energy storage the most promising for rapid implementation in Canada was found to be the storage of high temperature sensible heat. Although systems have been successfully deployed in other countries for many years, imported technology is not suitable in Canada due primarily to differences in housing types, and climatic conditions. The introduction of domestic heat storage units requires a cost incentive to the buyer which can occur through the establishment of time-of-day rates. The number of utilities offering "off peak" rates in the USA is increasing (39 states); there is no current "off peak" domestic rate in Canada.

The market for thermal heat storage is currently dominated by three manufacturers, namely,

- Hewitt (U.K.)
- Stiebel-Eltron (West Germany)
- Tennessee Plastic Inc. (TPI) (USA)

CONTRACT "HEAT STORAGE SYSTEMS FOR DOMESTIC AND INDUSTRIAL APPLICATIONS"

Chromalox Canada - Mr. C.R. Hollaman - Commenced February 1978

Subcontract - Ontario Research Foundation (ORF) - Dr. M.K. Murthy

OBJECTIVE The overall objective of this multiphase contract has been to select, design, fabricate, test and commercialize a thermal energy storage device primarily targeted at the domestic market.

PROGRESS In phase I the identification, selection and assessment of development requirements for an efficient heat storage medium was carried out, including a material evaluation program for both sensible and latent heat storage media and containment.

During phase II design requirements were developed for a sensible heat storage furnace suitable for Canadian conditions, model system characteristics were evaluated and sample iron oxide storage bricks were fabricated.

During phase III a 140 kWH prototype Mk I heat storage unit was designed, constructed and tested, and a new high density heat storage brick was developed to be incorporated into future Mk II prototypes. A versatile control system was developed to allow variable charging rates to an optimum capacity dependent on predicted requirements. The versatility of the control is an important feature which has not received much attention in competitor designs,

it allows accommodation to different control strategies of various electric utilities as well as a stand-alone capability. Tests were conducted by Chromalox and by Ontario Hydro. Five units have since been purchased by Ontario Hydro and are being field tested.

In Phase IV, characterization of the storage bricks with respect to thermal, physical, chemical and electric properties was carried out by ORF. A first stage optimization of the storage units was made by Chromalox and several Mk II furnaces incorporating the new bricks were constructed for laboratory testing.

Under Phase V, the design and technology of the heat storage devices was advanced in terms of cost, regulatory requirements and performance. The Mk II second generation prototype using "Chromalite" heat storage material produced by ORF was designed, constructed and several models of different sizes were tested, including one unit in an NRC test house at Ottawa, made available by NRC Division of Building Research.

As of fiscal year 1983/1984 funding for this program was assumed by the Conservation Task of OERD under the Buildings Space Heating program.

Under Phase VI further design/development was carried out to overcome deficiencies identified during the Phase V testing of Mark II units. Improvements were incorporated in a Mark III model which was evaluated for safety and performance during the 1983/1984 winter season. Mark III demonstration

units were placed in private dwellings in conjunction with utility test programs as follows:

- Two of Mark II (Phase V) prototypes included in Ontario Hydro load management program.
- Two of 120 kWh Mark III units incorporated in ongoing field tests with American Electric Power, Columbus, Ohio, USA
- One 120 kWh and one 175 kWh Mark III unit with United Power Association, Elk River, Minn., U.S.A.

Agreements with these Utilities provide for data feedback to Chromalox and to NRC. Positive comment was received from both the utilities and the home owners involved in this demonstration program.

CURRENT Mark III demonstration in field tests was successfully continued during the winter season of 1984/85 and a request was received that the furnaces be allowed to remain at their present locations.

FUTURE A key factor in the commercialization of these heat storage units is the setting of a time-of-day rate for electricity as an incentive to home-owner purchase of the equipment.

Significant export potential is expected to countries where requirements exist that are similar to those in Canada, such as northern states of U.S.A, and where time-of-day rates are already in effect.

INTERNATIONAL ENERGY AGENCY

The International Energy Agency is an autonomous body within the Organization of Economic Cooperation and Development. Canada participates in cooperative programs under the Hydrogen Implementing Agreement signed in October 1977. The other participants include many European countries as well as Japan and USA.

The accompanying table on page 119 indicates the breakdown of the I.E.A. Hydrogen Program into Tasks, and the table on page 120 shows the program participation and national representation.

The International Energy Agency Cooperative Program on Hydrogen was the subject of a presentation made at the 5th World Hydrogen Energy Conference, Toronto, 1984 by J.R. Whitehead and J.B. Taylor.

It should be noted that the Canadian representative, J.B. Taylor of NRC, was chairman of the Executive Committee. By tradition, this also required Canada to provide the committee secretariat. Future Canadian activities under the IEA Hydrogen agreement are uncertain. A notice of withdrawal has been submitted which could become effective in March 1986. Decisions with respect to continuation rest with the Department of Energy Mines and Resources who are the government signatories to the agreement.

CONTRACT ESTABLISHMENT AND OPERATION OF A SECRETARIAT FOR THE HYDROGEN EXECUTIVE COMMITTEE OF THE INTERNATIONAL ENERGY AGENCY

Dr. J.R. Whitehead - Ottawa
Commenced June 1984

OBJECTIVE Under this contract, provision was made for:

- Communications between the operating agents, the committee chairman and the IEA Secretariat, Paris.

- Advice on procedures, actions and protocol.

- Participation in program planning, implementation and review.

PROGRESS This contract was not renewed at its expiry date of November 1985. The continuing requirement was accommodated under the following contract.

CONTRACT TECHNO ECONOMIC ANALYSIS AND PROGRAM EVALUATION (INTERNATIONAL ENERGY AGENCY HYDROGEN IMPLEMENTATION)

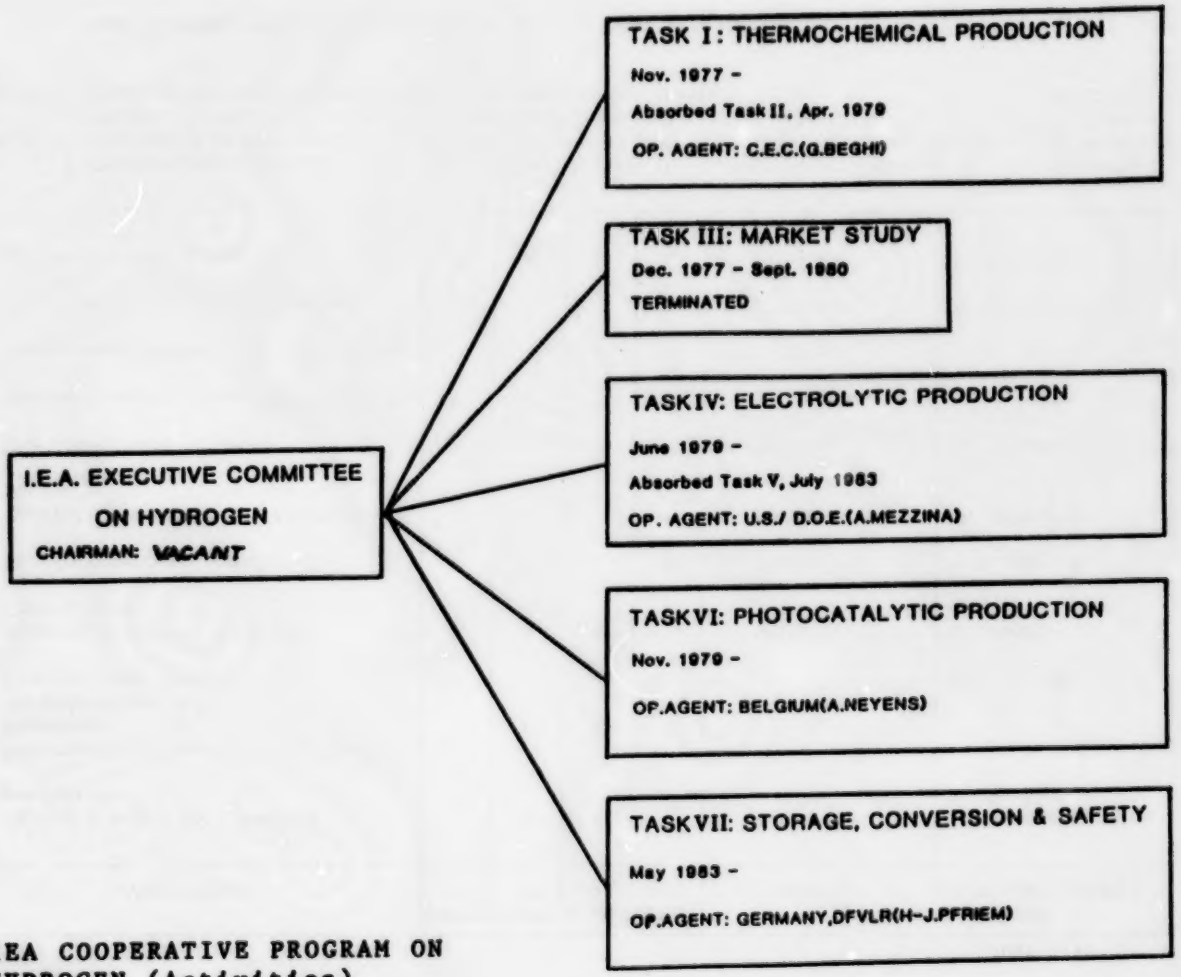
Hydrogen Industries Council (HIC) - Mr. R. Champagne

OBJECTIVE This contract calls for two major independent activities -

1. The HIC will assume responsibility providing the Secretariat to the IEA Executive Committee as previously carried out through the contract above.
2. HIC will carry out the planning and organization for a new task "Techno-Economic Analysis" to be presented to the IEA for consideration as Task VIII.

PROGRESS The Canadian IEA Executive Committee representative (and Committee Chairman) resigned in November 1985. The secretariat has continued to function at a reduced level of activity to allow an orderly transfer to a new committee chairman which is scheduled to be selected by the committee at its next meeting in May 1985.

Due to unavailability of funds the H&ES program support of objective 2 was reduced to compensation for travel and secretariat costs incurred in the planning phase of the new task.



IEA COOPERATIVE PROGRAM ON HYDROGEN (Activities)

JUNE 1985

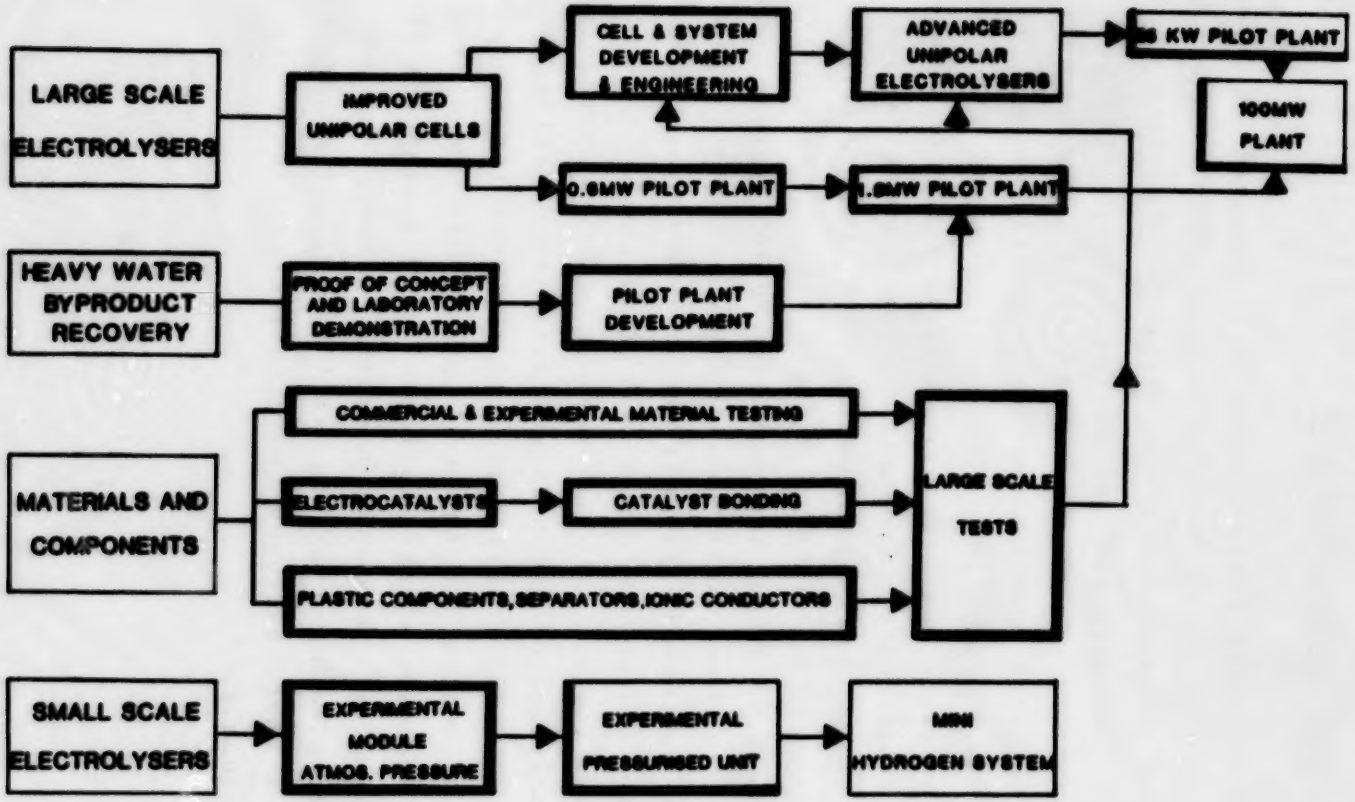
COUNTRY	PARTICIPANT	PARTICIPATION IN TASKS I	IV	VI	VII	EXECUTIVE COMMITTEE MEMBER	ALTERNATE MEMBER
BELGIUM	Centre d'étude de l'énergie nucléaire		X	X		F. Altdorfer	H. Vandenborre or M. Reniers
CANADA	Department of Energy, Mines and Resources Noranda Mines Ltd. Electrolyser Corp.		X	X	X		A.K. Stuart
CEC	Commission of the European Communities	X	X	X		A. Strub	G. Beghi
GERMANY	Kernforschungsanlage Jülich	X	X		X	N. Stump	B.D. Struck
ITALY	Comitato Nazionale per L'Energia Nucleare		X			S. Ferrari	S. Sabbadini
JAPAN	The Government of Japan	X	X		X	T. Hirano	H. Irisawa
SWEDEN	Energy Research Commission				X	B. Finnström	-
SWITZERLAND	Département Fédéral de l'Intérieur			X	X	P.E. Zinsli	-
UNITED KINGDOM	The City University of London		X			A.C. Tseung	K.E. Langley
U.S.A.	US Department of Energy	X	X	X	X	J.J. Brogan	M. Gurevich

Operating Agents: Task I : Thermochemical Production: CEC, acting through the Joint Research Centre G. Beghi
Task IV : Electrolytic Production: US DOE, acting through Brookhaven National Laboratory A. Mezzina
Task VI : Photocatalytic Production: Katholieke Universiteit Leuven, Belgium A. Neyens
Task VII: Storage, Conversion and Safety: Germany acting through DFVLR H.J. Pfrim

IEA HYDROGEN PROGRAM (Participation and National Representation)

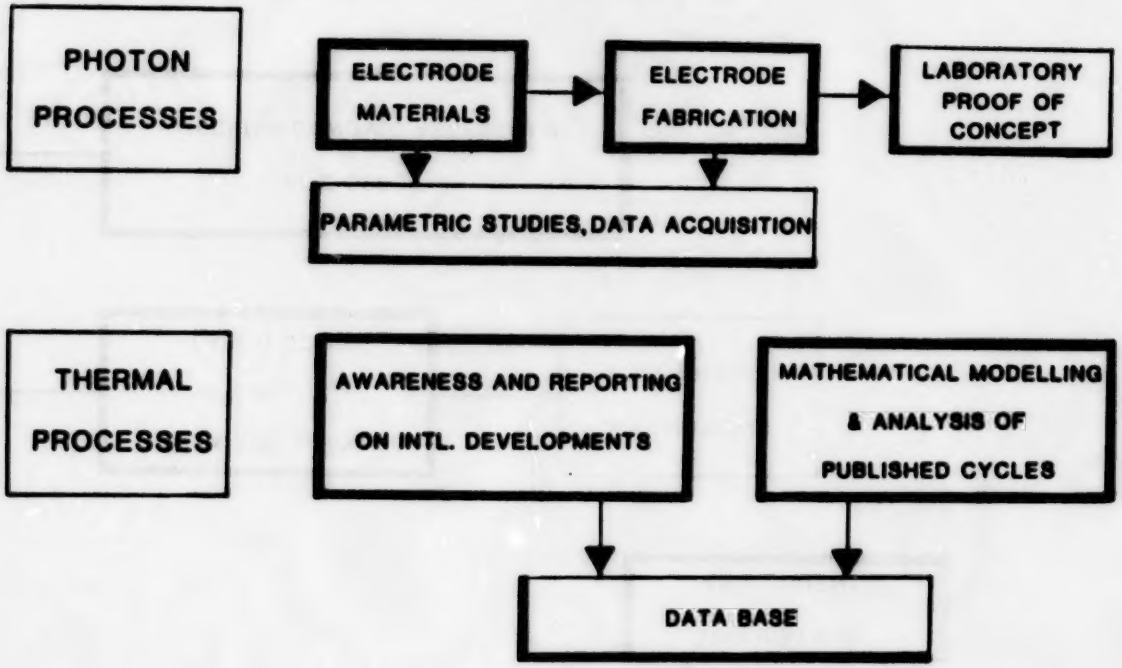
5th WORLD HYDROGEN ENERGY CONFERENCE

The 5th World Hydrogen Energy Conference was held in Toronto, Canada between July 15 to 20 1984. This biennial conference was hosted and sponsored by the National Research Council Canada through the Hydrogen and Energy Storage Program. The National Organizing Committee, under the chairmanship of J.B. Taylor included representation from all sectors of the Canadian hydrogen community. The conference was attended by delegates from thirty one nations. Full advantage was taken of this unique opportunity to establish communications and good will between the diverse hydrogen interests both within Canada and at an international level. Perhaps one of the significant differences between this and earlier World Hydrogen Energy Conferences was the increased profile of the industrial participation, promoted strongly by the Hydrogen Industries Council. The conference theme was Transitions to Hydrogen which was the subject of the keynote address presented by M. Richard Champagne of the Hydrogen Industry Council. The tone of the conference inevitably reflected the need for a new focus due to recent shifts in national priorities away from the dominant concern over energy which prevailed during the 1970's. The idea of an all pervading hydrogen economy has at least temporarily receded and thoughts are being directed more to the special niches where hydrogen characteristics can be exploited most advantageously.

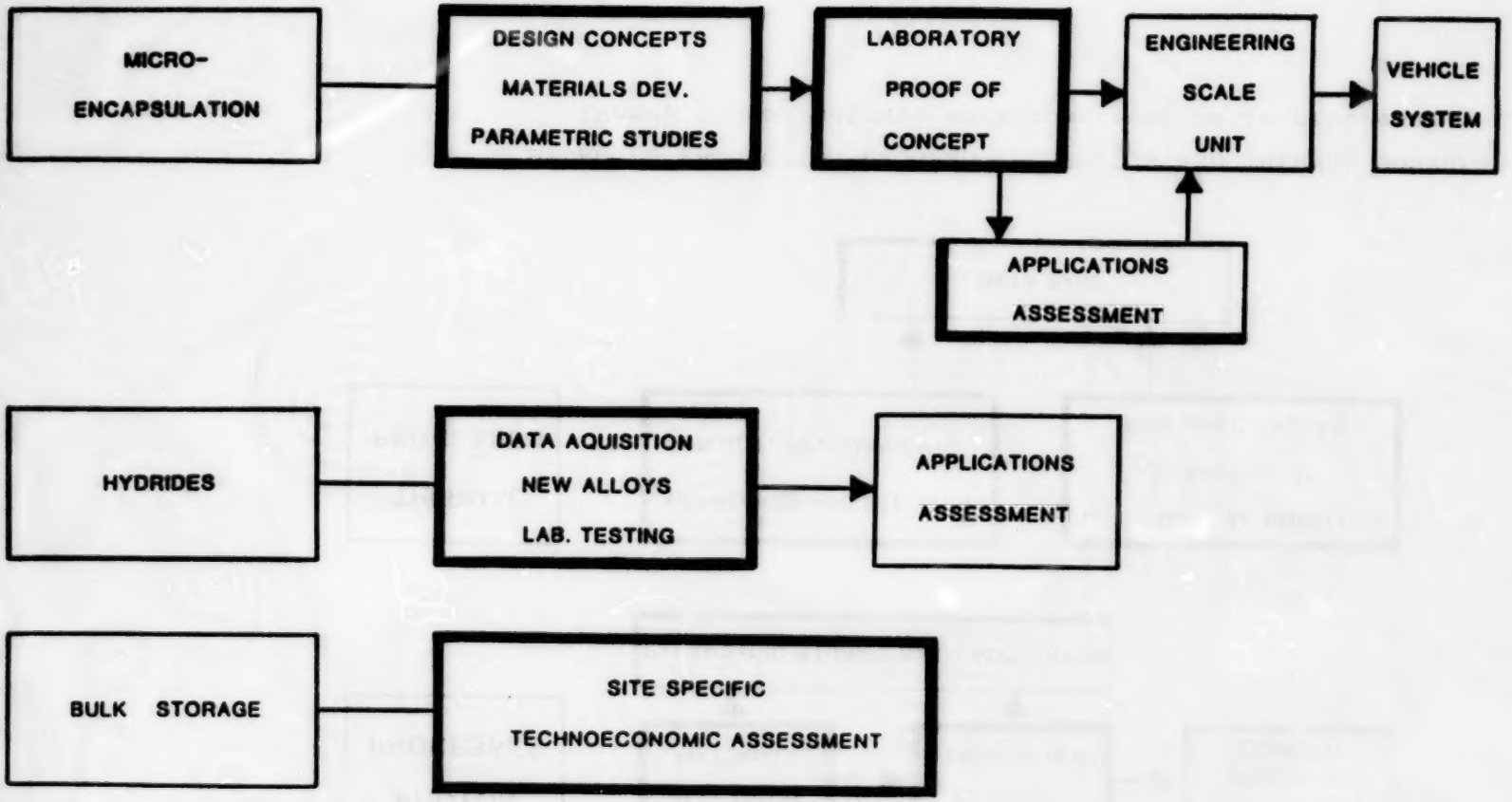


HYDROGEN PRODUCTION PROGRAM - ELECTROLYSIS

(Heavy lines indicate work completed or in progress)



HYDROGEN PRODUCTION PROGRAM - PHOTON AND THERMAL SOURCES
(Heavy lines indicate work completed or in progress)



HYDROGEN STORAGE PROGRAM

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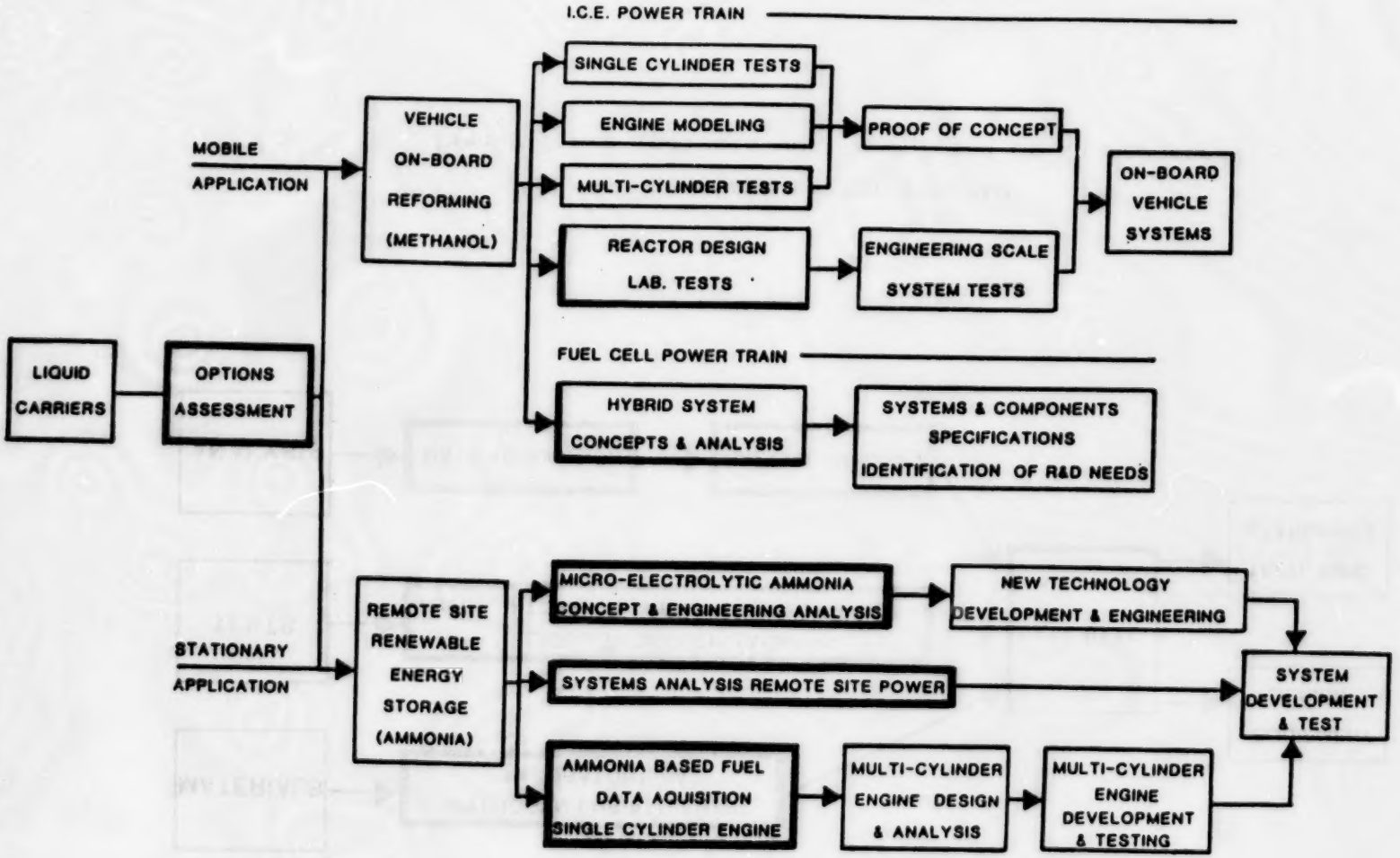
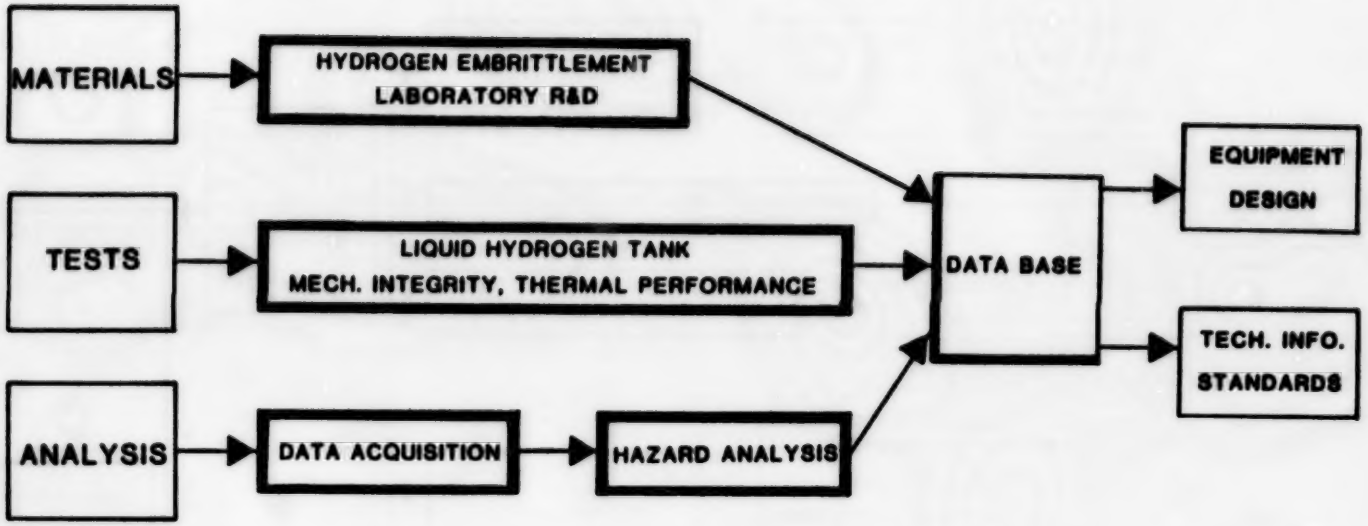

I.C.E. POWER TRAIN
SINGLE CYLINDER TESTS
ENGINE MODELING
MULTI-CYLINDER TESTS
PROOF OF CONCEPT
ON-BOARD VEHICLE SYSTEMS
MOBILE APPLICATION
VEHICLE ON-BOARD REFORMING (METHANOL)
REACTOR DESIGN LAB. TESTS
ENGINEERING SCALE SYSTEM TESTS
LIQUID CARRIERS
OPTIONS ASSESSMENT
FUEL CELL POWER TRAIN
HYBRID SYSTEM CONCEPTS & ANALYSIS
SYSTEMS & COMPONENTS SPECIFICATIONS IDENTIFICATION OF R&D NEEDS
MICRO-ELECTROLYTIC AMMONIA CONCEPT & ENGINEERING ANALYSIS
NEW TECHNOLOGY DEVELOPMENT & ENGINEERING
STATIONARY APPLICATION
REMOTE SITE RENEWABLE ENERGY STORAGE (AMMONIA)
SYSTEMS ANALYSIS REMOTE SITE POWER
SYSTEM DEVELOPMENT & TEST
AMMONIA BASED FUEL DATA AQUISITION SINGLE CYLINDER ENGINE
MULTI-CYLINDER ENGINE DESIGN & ANALYSIS
MULTI-CYLINDER ENGINE DEVELOPMENT & TESTING

HYDROGEN STORAGE (LIQUID CARRIERS) PROGRAM

(Heavy lines indicate work completed or in progress)



HYDROGEN SAFETY PROGRAM

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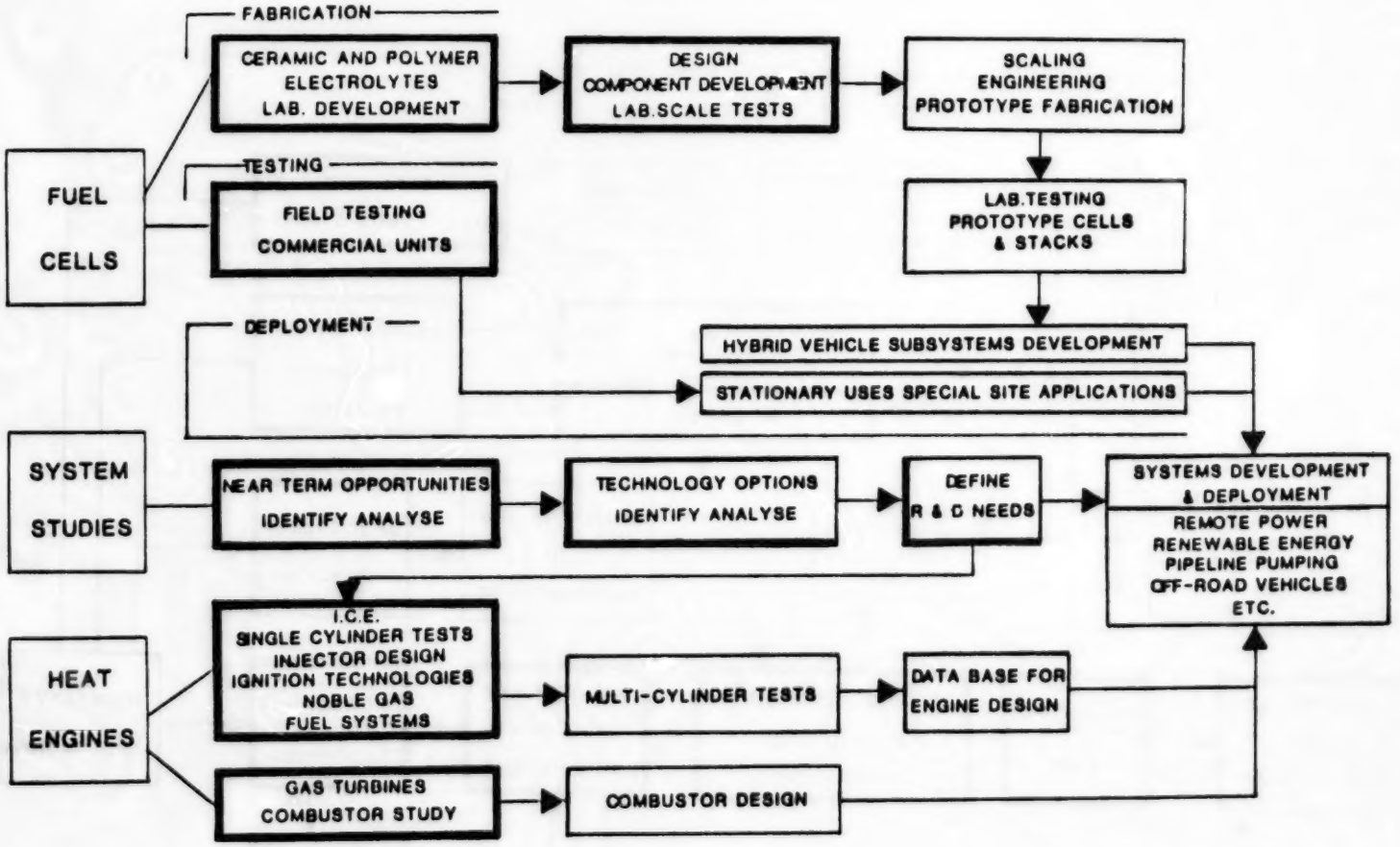

HYDROGEN UTILIZATION PROGRAM

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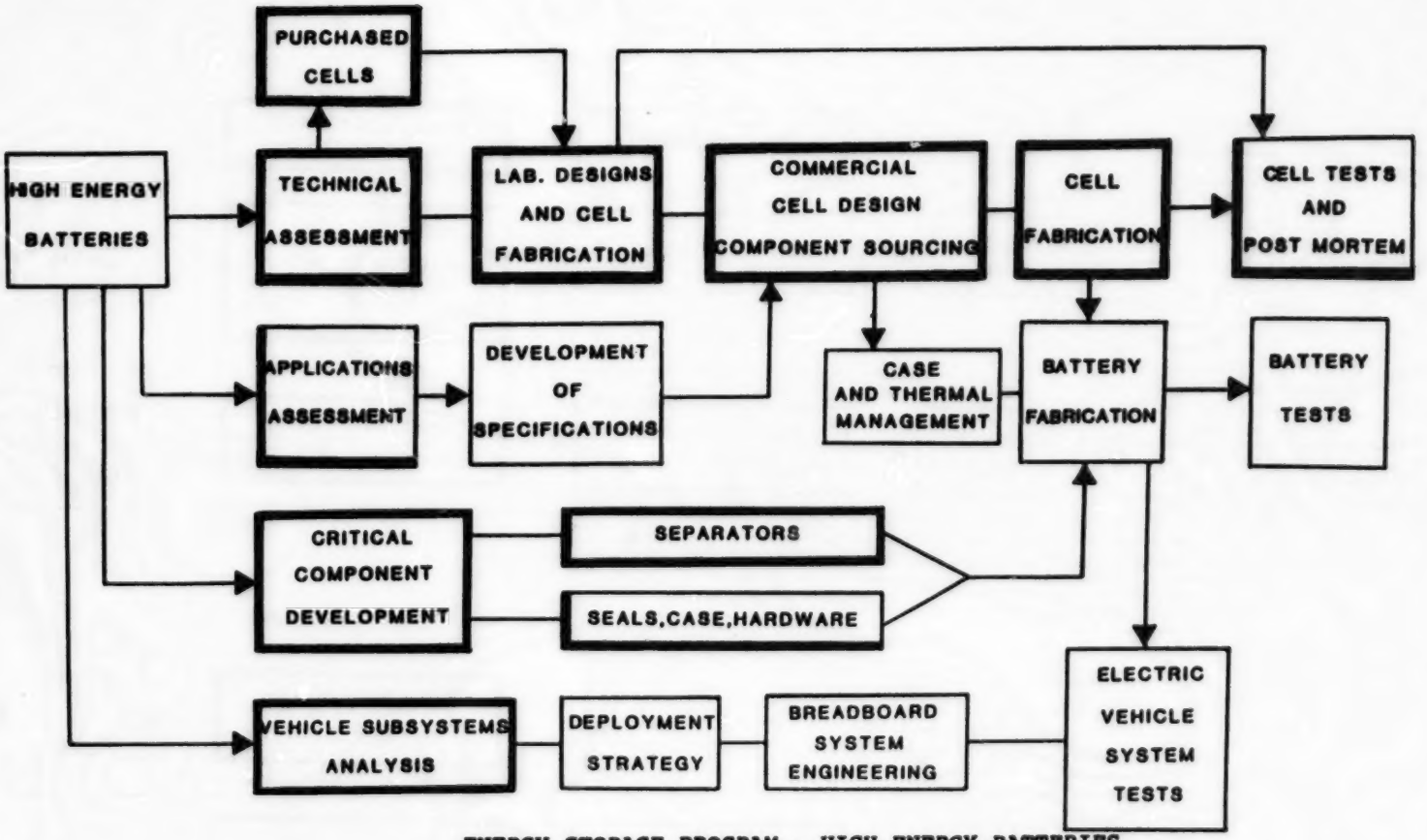

ENERGY STORAGE PROGRAM - HIGH ENERGY BATTERIES
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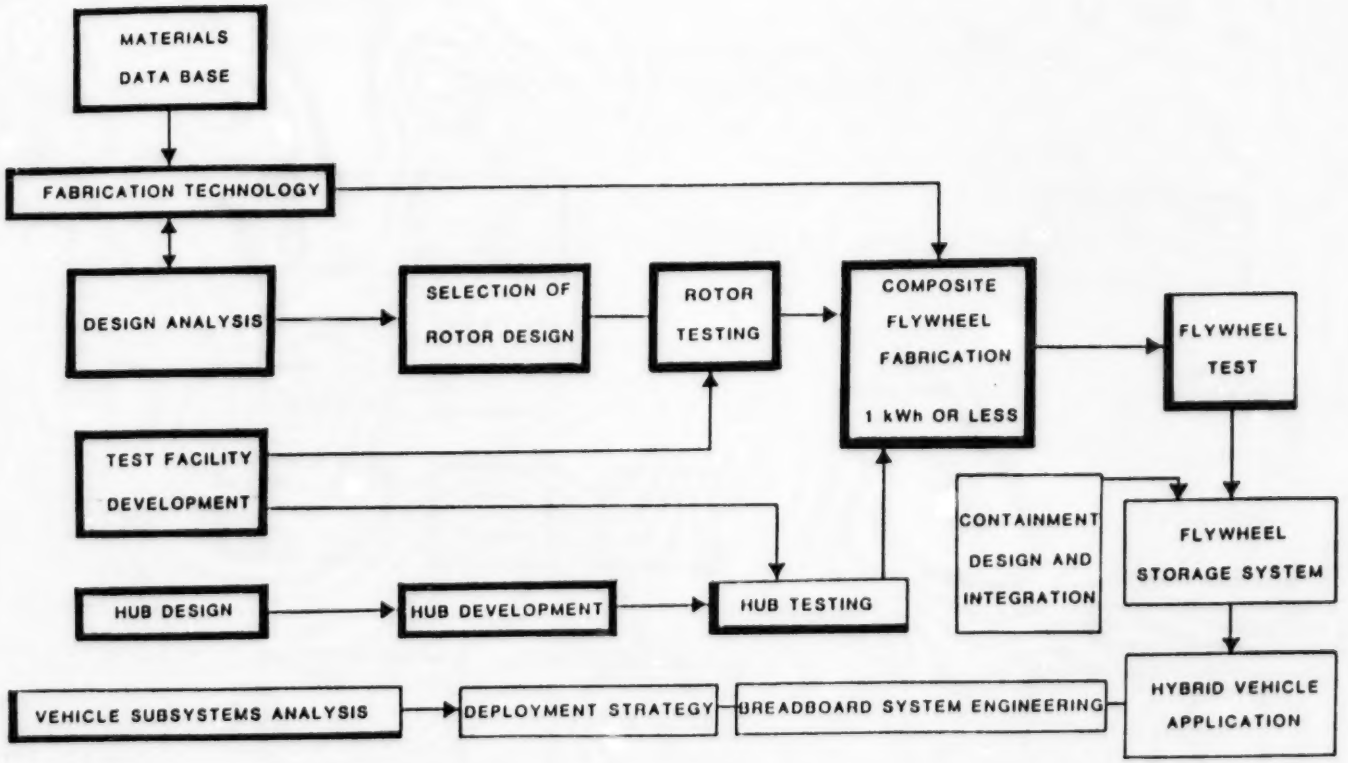
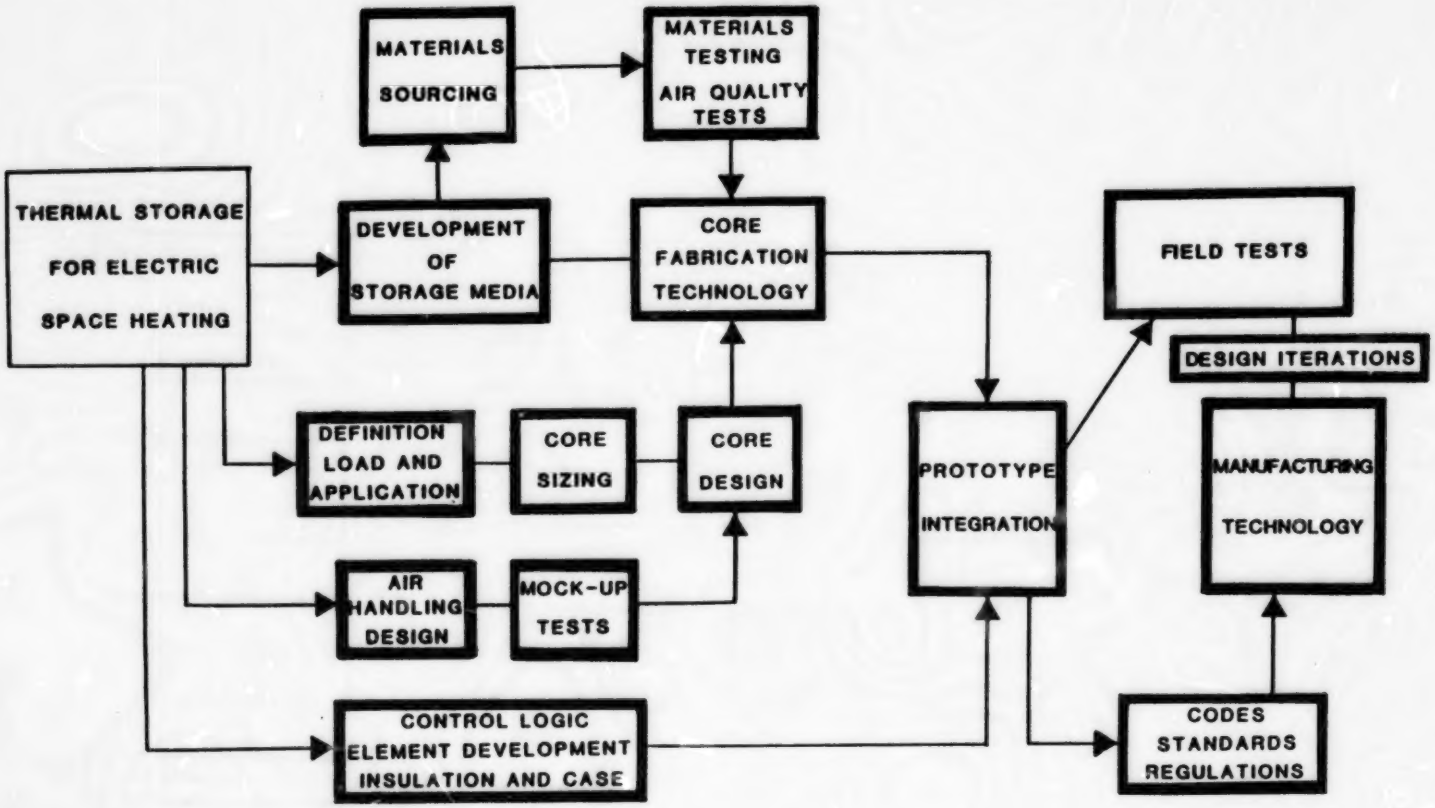


ENERGY STORAGE PROGRAM - FLYWHEEL

(Heavy lines indicate work completed or in progress)



ENERGY STORAGE PROGRAM - THERMAL

(Heavy lines indicate work completed or in progress)

PUBLICATIONS AND PRESENTATIONS

Listed below are recent or previously not reported publications and presentations resulting from research supported in full or in part by the Hydrogen and Energy Storage Program. A back-listing of work previous to 1983 was included in the May 1984 report. The listing is in alphabetical order of the contract performer followed in parenthesis by the page numbers of this report to which the work relates.

Atlantic Industrial Research Institute (8)

- G. Murphy, W. Manuel, K.M. Castelliz & H.W. King "Electrocatalysts for Oxygen Evolution - Phase V - Final Report", Nov. (1984).

Ballard Technologies Corp. (13)

- A.E. Steck, "Development and Characterization of Aromatic Ionomer Membranes" IEA Hydrogen Task IV Workshop, July 1985.

Blue Mountain Pottery Ltd. (96)

- R. Miller "High Temperature Battery Separator Development - Phase I - Final Report", June 1983

- R. Miller, "High Temperature Battery Separator Development - Phase II - Final Report", Nov. 1984

Canatom Inc. (66)

- Materials for Gaseous Hydrogen Containment - Final Report", March (1985)

- K.M. Kalyanam & A.R. Lyle, "Hydrogen Bulk Storage - Phase I - Report", August (1983)

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- S.M. Ahmed, "The Canadian Contribution to the IEA Work on Hydrogen Production by Photoelectrolysis of Water". Hydrogen Energy Progress V, 1013-1026 (1984).

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- T.A. Wheat, P.S. Nicholson and M. Nagai, "Preparation of a Precursor Powder for the Manufacture of a Ceramic Hydrogen Ion Conductor", Can. Patent 1,180,881 granted 28 April 1984, issued 15 Jan. 1985.

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- A.K. Kuriakose, T.A. Wheat, A. Ahmad and J.D. Canaday "Hardness of Beta-alumina and Zirpsios", presented to

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- A. Ahmad, J.D. Canaday, T.A. Wheat and A.K. Kuriakose, "A Computer-controlled Data Acquisition System for Electrical-Electrochemical Characterization of Ceramic Materials", presented to the Annual Meeting of the Canadian Ceramic Society, Toronto 1984.

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- A. Ahmad, J.D. Canaday, T.A. Wheat and A.K. Kuriakose, "A Computer-controlled Data Acquisition System for Electrical-Electrochemical Characterization of Ceramic Materials", ERP/MSL 87-17(OP).

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- J.D. Canaday, T.A. Wheat, A.K. Kuriakose and A. Ahmad, "Gas Phase Relations for Protonic Solid Electrolyte Fuel Cells", ERP/MSL 84-125(J).

- J.D. Canaday, T.A. Wheat, A.K. Kuriakose and A. Ahmad, "A Microcomputer System for Fuel Cell Measurements", ERP/MSL 84-154(J).

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- A. Stockman & P.S. Nicholson, "Ultrasonic Scattering and Voids in Glass: Theory & Practice", presented to the 82nd Annual Meeting of the Canadian Ceram. Soc. Toronto, March 1984.

- K. Yamashita & P.S. Nicholson, "Alkali (Na, K, Cs) and Hydronium Ion Conducting Rare Earth Silicate ($M_5RSi_4O_{12}$): M = Na, K, H_3O; R = Gd, Y)", presented to 86th Annual Meeting Amer. Ceram. Soc., Pittsburgh, 1 May 1984.

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- Gasicon and Yasicon patents filed.

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- R.E. Knowlton, "An Investigation of the Safety Aspects in the Use of Hydrogen as a Ground Transportation Fuel" Hydrogen Energy Progress V, 1881-1892, (1984).

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- A. Stawsky et al., "On Board Hydrogen Generation from Liquid Carriers - Final Report", February 1984.

Exergy Research Corporation (31)

- S.Z. Baykara & E. Bilgen, "Hydrogen Production by Solar Thermolysis of Water". Hydrogen Energy Progress V, 1111-1122, (1984).

- C. Bilgen & E. Bilgen, "Solar Hydrogen Production Using the Sulphur-Iodine Thermochemical Process", Hydrogen Energy Progress V, 517-528, (1984).

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- R.D. Champagne, D.R. Hay, P. Hoffman, R.L. LeRoy, C. Salama & J.B. Taylor, "Transitions to Hydrogen", Hydrogen Energy Progress V, 11-20, 1984.

Institute for Hydrogen Systems (69)

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- R. Shand, W. Thomas, G. Reese & C. Kristiansen, "Experimental Development of an Ammonia Fueled Engine - Final Report" May 1985.

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- E. Besso, Ph.D. Thesis, McGill University, Montreal, 1984.

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J.B. Taylor, J.E.A. Alderson, K.M. Kalyanam, A.R. Lyle & L.A. Phillips, "Technical and Economic Assessment of Methods for the Storage of Large Quantities of Hydrogen". Submitted for publication to Int. J. Hydrogen Energy.

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- M. Hammerli, "An Overview of the Canadian Contributions to Task IV of the IEA Hydrogen Implementing Agreement", IEA Hydrogen Task IV, July 1985.

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- M.B.I. Janjua & R.L. LeRoy, "Electrocatalyst Performance in Industrial Water Electrolysers". Hydrogen Energy Progress V, 605-617, (1984).

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- B.G. Sellars, K.L. Yan & J. Lo, "Hollow Microcapsules for Hydrogen Technology". Presentation for the IEA Hydrogen Task VII Technical Workshop, Bern, Switzerland, June (1985).

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- N. Middlemiss, "Lithium Ionic Conductors", Dec. 1981.

Pratt & Whitney Canada Inc. (83)

- F. Shum & P. Sampath, "Hydrogen Combustion Research - Final Report", April 1984.

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- A.E. Steck & H.L. Yeager, "Evaluation of Aromatic Ionomer Separators for Use in Advanced Alkaline Water Electrolyzers", Hydrogen Energy Progress V, 561-569, 1984.

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and pressures", J. Electrochem. Soc., 130, 1297-1300, (1983).

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HYDROGEN & ENERGY STATUS REPORT NRC 1985

LIST OF CONTRACTS AND FUNDING

Page	*	Subject	FUNDING($1000) 83/84	84/85	85/86
8	(IV)	Cathodic Catalysts (Atlantic Industrial Res. Inst.)	75.9	58.4	-
13	(IV)	Solid Polymer Electrolytes(Daychem)	122.6	153.2	80.0
		(McGill U.)	67.6	87.6	46.1
		(U. of Calgary)	119.2	90.3	-
		(Ballard)	-	94.3	78.9
16	(IV)	Solid Polymer Electrolytes(Carleton U./NRC)	40.0	41.5	-
19	(IV)	High Temperature Electrolytes(Queen's U.)	131.2	161.7	77.5
		Solid Electrolyte Testing(McMaster U.)	23.7	-	-
10	(IV)	Multi-electron Electrocatalyst(York U.)	-	37.6	19.7
23	(IV)	Electrolyser Test Cell(Noranda)	94.0	174.0	42.9
28		Electrolyser Development(Noranda)	365.5	459.9	404.6
31		Thermochemical Production(Exergy)	67.8	68.4	-
34	(IV)	Small Electrolyser Tests(NRC/Life Systems)	62.0	-	-
35		High Temperature Materials(McMaster U.)	40.0	39.9	-
42		Bulk Storage(CANATOM)	162.0	38.0	-
47	(VII)	Microencapsulation(Ontario Res. Foundation)	201.8	232.1	33.5
-	(VII)	Liquid Carriers(Engelhard)	55.5	-	-
56		Liquid Carriers(O.R.F.)	-	30.0	-
58	(VII)	Ammonia Engine(Manitoba Research Council)	35.2	171.3	-
61		Micro Ammonia Plant(Associated Kellogg Ltd)	-	61.0	-
64		Hydrogen Safety Committee Secretariat (Chemetics)	12.5	25.4	17.8
66	(VII)	Materials for gaseous Hydrogen Containment (CANATOM)	-	102.6	-
55		Ammonia Safety (Chemetics)	29.9	-	-
69	(VII)	Liquid Hydrogen Tank Tests(IHS)	-	125.9	99.0

Page	*	Subject	FUNDING($1000)		
			83/84	84/85	85/86
-		Fuel Cell Purchase(United Technologies)	654.3	-	-
73		U.T. Fuel Cell Data Acquisition & Analysis (Sci. App. Inc.)	-	49.0	40.0
71		Fuel Cell Testing (B.C. Hydro)	-	274.0	-
		Fuel Cell Testing & Shipping (I.H.S.)	-	43.6	-
-		Contribution(Institute for Hydrogen Systems	401.0	-	-
74		Solid Electrolyte Fuel Cell(CANMET/EMR)	600.0	660.0	368
77		SPE Fuel Cell(Defense Research Establishment, Ottawa/Ballard)	200.0	210.0	
80	(VII)	Hydrogen Engine(U. of Toronto)	130.3	27.5	-
82	(VII)	Hydrogen Engine(NRC)	98.6	70.0	-
83	(VII)	Gas Turbine (Pratt & Whitney)	67.0	-	-
86	(VII)	System Analysis(Chemetics)	15.7	200.9	6.5
121		Transitions to Hydrogen(Escher Foster, Technology in Support of 5th World Hydrogen Energy Conf.)	20.5	4.5	-
-		Tidal Energy Storage(Simons Energy Consultants)	1.8	-	-
93		Li/FeS Bi-cell Fabrication(The Electrofuel Manufacturing Co.)	473.5	517.5	288.8
-		Boron Nitride(Blue Mountain Pottery)	208.2	97.8	-
96		BN Separators(Electrofuel)	-	211.9	166.1
94		Battery Test Facility(DPEO)	30.0	43.0	-
99		Alcan Battery Vehicle(TDC)	-	110.0	-
102		Electrical Vehicle R&D(EMR)	200.0	53.0	-
104		EV's(Transport Canada)	100.0	142.0	-
104		Non-Hydrocarbon Subsystems(Davis Eng. Ltd.)	19.5	241.9	-
109		Flywheels(U. of Ottawa)	223.9	227.2	72.6
113		Heat Storage(Chromalox)	433.4	6.3	18.4
117		IEA Secreteriat (HIC)	34.4	24.0	8.0
116		IEA Secretariat (R. Whitehead)	-	21.7	-